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# VAX MACRO and Instruction Set Reference Manual

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This document describes the features of the VAX MACRO instruction set and assembler. It includes a detailed description of MACRO directives and instructions, as well as information about MACRO source program syntax.

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# Contents

|  |      |
|--|------|
| <b>Preface</b> .....                               | xv   |
| <br><b>VAX MACRO Language</b>                      |      |
| <b>1 Introduction</b>                              |      |
| <b>2 VAX MACRO Source Statement Format</b>         |      |
| 2.1 Label Field .....                              | 2-2  |
| 2.2 Operator Field .....                           | 2-3  |
| 2.3 Operand Field .....                            | 2-3  |
| 2.4 Comment Field .....                            | 2-3  |
| <br><b>3 Components of MACRO Source Statements</b> |      |
| 3.1 Character Set .....                            | 3-1  |
| 3.2 Numbers .....                                  | 3-2  |
| 3.2.1 Integers .....                               | 3-3  |
| 3.2.2 Floating-Point Numbers .....                 | 3-3  |
| 3.2.3 Packed Decimal Strings .....                 | 3-4  |
| 3.3 Symbols .....                                  | 3-4  |
| 3.3.1 Permanent Symbols .....                      | 3-4  |
| 3.3.2 User-Defined Symbols and Macro Names .....   | 3-5  |
| 3.3.3 Determining Symbol Values .....              | 3-5  |
| 3.4 Local Labels .....                             | 3-6  |
| 3.5 Terms and Expressions .....                    | 3-8  |
| 3.6 Unary Operators .....                          | 3-9  |
| 3.6.1 Radix Control Operators .....                | 3-10 |
| 3.6.2 Textual Operators .....                      | 3-11 |
| 3.6.2.1 ASCII Operator .....                       | 3-11 |
| 3.6.2.2 Register Mask Operator .....               | 3-12 |
| 3.6.3 Numeric Control Operators .....              | 3-13 |
| 3.6.3.1 Floating-Point Operator .....              | 3-13 |
| 3.6.3.2 Complement Operator .....                  | 3-13 |
| 3.7 Binary Operators .....                         | 3-14 |
| 3.7.1 Arithmetic Shift Operator .....              | 3-14 |
| 3.7.2 Logical AND Operator .....                   | 3-15 |
| 3.7.3 Logical Inclusive OR Operator .....          | 3-15 |
| 3.7.4 Logical Exclusive OR Operator .....          | 3-15 |
| 3.8 Direct Assignment Statements .....             | 3-15 |
| 3.9 Current Location Counter .....                 | 3-16 |

## 4 Macro Arguments and String Operators

|       |                                   |      |
|-------|-----------------------------------|------|
| 4.1   | Arguments in Macros               | 4-1  |
| 4.2   | Default Values                    | 4-2  |
| 4.3   | Keyword Arguments                 | 4-2  |
| 4.4   | String Arguments                  | 4-3  |
| 4.5   | Argument Concatenation            | 4-5  |
| 4.6   | Passing Numeric Values of Symbols | 4-6  |
| 4.7   | Created Local Labels              | 4-6  |
| 4.8   | Macro String Operators            | 4-7  |
| 4.8.1 | %LENGTH Operator                  | 4-7  |
| 4.8.2 | %LOCATE Operator                  | 4-8  |
| 4.8.3 | %EXTRACT Operator                 | 4-10 |

## 5 VAX MACRO Addressing Modes

|       |                             |      |
|-------|-----------------------------|------|
| 5.1   | General Register Modes      | 5-1  |
| 5.1.1 | Register Mode               | 5-3  |
| 5.1.2 | Register Deferred Mode      | 5-4  |
| 5.1.3 | Autoincrement Mode          | 5-4  |
| 5.1.4 | Autoincrement Deferred Mode | 5-5  |
| 5.1.5 | Autodecrement Mode          | 5-6  |
| 5.1.6 | Displacement Mode           | 5-6  |
| 5.1.7 | Displacement Deferred Mode  | 5-8  |
| 5.1.8 | Literal Mode                | 5-9  |
| 5.2   | Program Counter Modes       | 5-10 |
| 5.2.1 | Relative Mode               | 5-10 |
| 5.2.2 | Relative Deferred Mode      | 5-11 |
| 5.2.3 | Absolute Mode               | 5-12 |
| 5.2.4 | Immediate Mode              | 5-12 |
| 5.2.5 | General Mode                | 5-14 |
| 5.3   | Index Mode                  | 5-14 |
| 5.4   | Branch Mode                 | 5-16 |

## 6 VAX MACRO Assembler Directives

|             |      |
|-------------|------|
| .ADDRESS    | 6-4  |
| .ALIGN      | 6-5  |
| .ASCIIx     | 6-7  |
| .ASCIC      | 6-8  |
| .ASCID      | 6-9  |
| .ASCII      | 6-10 |
| .ASCIZ      | 6-11 |
| .BLKx       | 6-12 |
| .BYTE       | 6-14 |
| .CROSS      | 6-16 |
| .DEBUG      | 6-18 |
| .DEFAULT    | 6-19 |
| .D_FLOATING | 6-20 |
| .DISABLE    | 6-21 |
| .ENABLE     | 6-22 |
| .END        | 6-25 |

|                |      |
|----------------|------|
| .ENDC          | 6-26 |
| .ENDM          | 6-27 |
| .ENDR          | 6-28 |
| .ENTRY         | 6-29 |
| .ERROR         | 6-31 |
| .EVEN          | 6-33 |
| .EXTERNAL      | 6-34 |
| .F_FLOATING    | 6-35 |
| .G_FLOATING    | 6-36 |
| .GLOBAL        | 6-37 |
| .H_FLOATING    | 6-38 |
| .IDENT         | 6-39 |
| .IF            | 6-40 |
| .IF_x          | 6-43 |
| .IIF           | 6-46 |
| .IRP           | 6-47 |
| .IRPC          | 6-49 |
| .LIBRARY       | 6-51 |
| .LINK          | 6-52 |
| .LIST          | 6-55 |
| .LONG          | 6-56 |
| .MACRO         | 6-57 |
| .MASK          | 6-59 |
| .MCALL         | 6-60 |
| .MDELETE       | 6-61 |
| .MEXIT         | 6-62 |
| .NARG          | 6-63 |
| .NCHR          | 6-64 |
| .NLIST         | 6-65 |
| .NOCROSS       | 6-66 |
| .NOSHOW        | 6-67 |
| .NTYPE         | 6-68 |
| .OCTA          | 6-70 |
| .ODD           | 6-71 |
| .OPDEF         | 6-72 |
| .PACKED        | 6-74 |
| .PAGE          | 6-75 |
| .PRINT         | 6-76 |
| .PSECT         | 6-77 |
| .QUAD          | 6-81 |
| .REFn          | 6-82 |
| .REPEAT        | 6-83 |
| .RESTORE_PSECT | 6-85 |
| .SAVE_PSECT    | 6-86 |
| .SHOW          |      |

|                    |       |
|--------------------|-------|
| .NOSHOW .....      | 6-88  |
| .SIGNED_BYTE ..... | 6-90  |
| .SIGNED_WORD ..... | 6-91  |
| .SUBTITLE .....    | 6-93  |
| .TITLE .....       | 6-94  |
| .TRANSFER .....    | 6-95  |
| .WARN .....        | 6-98  |
| .WEAK .....        | 6-100 |
| .WORD .....        | 6-101 |

## VAX Data Types and Instruction Set

### 7 Terminology and Conventions

|     |                                   |     |
|-----|-----------------------------------|-----|
| 7.1 | Numbering .....                   | 7-1 |
| 7.2 | UNPREDICTABLE and UNDEFINED ..... | 7-1 |
| 7.3 | Ranges and Extents .....          | 7-1 |
| 7.4 | MBZ .....                         | 7-1 |
| 7.5 | RAZ .....                         | 7-2 |
| 7.6 | SBZ .....                         | 7-2 |
| 7.7 | Reserved .....                    | 7-2 |
| 7.8 | Figure Drawing Conventions .....  | 7-2 |

### 8 Basic Architecture

|        |                                       |      |
|--------|---------------------------------------|------|
| 8.1    | Basic Architecture .....              | 8-1  |
| 8.2    | VAX Addressing .....                  | 8-2  |
| 8.3    | Data Types .....                      | 8-2  |
| 8.3.1  | Byte .....                            | 8-2  |
| 8.3.2  | Word .....                            | 8-2  |
| 8.3.3  | Longword .....                        | 8-3  |
| 8.3.4  | Quadword .....                        | 8-3  |
| 8.3.5  | Octaword .....                        | 8-3  |
| 8.3.6  | F_floating .....                      | 8-4  |
| 8.3.7  | D_floating .....                      | 8-4  |
| 8.3.8  | G_floating .....                      | 8-5  |
| 8.3.9  | H_floating .....                      | 8-6  |
| 8.3.10 | Variable-Length Bit Field .....       | 8-6  |
| 8.3.11 | Character String .....                | 8-7  |
| 8.3.12 | Trailing Numeric String .....         | 8-8  |
| 8.3.13 | Leading Separate Numeric String ..... | 8-11 |
| 8.3.14 | Packed Decimal String .....           | 8-12 |
| 8.4    | Processor Status Longword (PSL) ..... | 8-13 |
| 8.4.1  | C Bit .....                           | 8-14 |
| 8.4.2  | V Bit .....                           | 8-14 |
| 8.4.3  | Z Bit .....                           | 8-14 |
| 8.4.4  | N Bit .....                           | 8-14 |
| 8.4.5  | T Bit .....                           | 8-14 |
| 8.4.6  | IV Bit .....                          | 8-14 |
| 8.4.7  | FU Bit .....                          | 8-14 |
| 8.4.8  | DV Bit .....                          | 8-15 |
| 8.5    | Permanent Exception Enables .....     | 8-15 |
| 8.5.1  | Divide by Zero .....                  | 8-15 |

|       |   |      |
|-------|---|------|
| 8.5.2 | Floating Overflow . . . . .                       | 8-15 |
| 8.6   | Instruction and Addressing Mode Formats . . . . . | 8-15 |
| 8.6.1 | Opcode Formats . . . . .                          | 8-15 |
| 8.6.2 | Operand Specifiers . . . . .                      | 8-15 |
| 8.7   | General Addressing Mode Formats . . . . .         | 8-16 |
| 8.7.1 | Register Mode . . . . .                           | 8-17 |
| 8.7.2 | Register Deferred Mode . . . . .                  | 8-17 |
| 8.7.3 | Autoincrement Mode . . . . .                      | 8-18 |
| 8.7.4 | Autoincrement Deferred Mode . . . . .             | 8-18 |
| 8.7.5 | Autodecrement Mode . . . . .                      | 8-19 |
| 8.7.6 | Displacement Mode . . . . .                       | 8-19 |
| 8.7.7 | Displacement Deferred Mode . . . . .              | 8-20 |
| 8.7.8 | Literal Mode . . . . .                            | 8-21 |
| 8.7.9 | Index Mode . . . . .                              | 8-23 |
| 8.8   | Summary of General Mode Addressing . . . . .      | 8-24 |
| 8.8.1 | General Register Addressing . . . . .             | 8-24 |
| 8.8.2 | Program Counter Addressing . . . . .              | 8-25 |
| 8.9   | Branch Mode Addressing Formats . . . . .          | 8-26 |

## 9 VAX Instruction Set

|       |   |      |
|-------|---|------|
| 9.1   | Introduction to the VAX Instruction Set . . . . .     | 9-1  |
| 9.2   | Instruction Descriptions . . . . .                    | 9-1  |
| 9.2.1 | Integer Arithmetic and Logical Instructions . . . . . | 9-5  |
|       | ADAWI . . . . .                                       | 9-7  |
|       | ADD . . . . .   | 9-8  |
|       | ADWC . . . . .  | 9-9  |
|       | ASH . . . . .   | 9-10 |
|       | BIC . . . . .   | 9-11 |
|       | BIS . . . . .   | 9-12 |
|       | BIT . . . . .   | 9-13 |
|       | CLR . . . . .   | 9-14 |
|       | CMP . . . . .   | 9-15 |
|       | CVT . . . . .   | 9-16 |
|       | DEC . . . . .   | 9-17 |
|       | DIV . . . . .   | 9-18 |
|       | EDIV . . . . .  | 9-19 |
|       | EMUL . . . . .  | 9-20 |
|       | INC . . . . .   | 9-21 |
|       | MCOM . . . . .  | 9-22 |
|       | MNEG . . . . .  | 9-23 |
|       | MOV . . . . .   | 9-24 |
|       | MOVZ . . . . .  | 9-25 |
|       | MUL . . . . .   | 9-26 |
|       | PUSHL . . . . .                                       | 9-27 |
|       | ROTL . . . . .  | 9-28 |
|       | SBWC . . . . .  | 9-29 |
|       | SUB . . . . .   | 9-30 |
|       | TST . . . . .   | 9-31 |
|       | XOR . . . . .   | 9-32 |

|         |  |      |
|---------|--|------|
| 9.2.2   | Address Instructions                   | 9-33 |
|         | MOVA                                   | 9-34 |
|         | PUSHA                                  | 9-35 |
| 9.2.3   | Variable-Length Bit Field Instructions | 9-36 |
|         | CMP                                    | 9-38 |
|         | EXT                                    | 9-39 |
|         | FF                                     | 9-40 |
|         | INSV                                   | 9-41 |
| 9.2.4   | Control Instructions                   | 9-42 |
|         | ACB                                    | 9-44 |
|         | AOBLEQ                                 | 9-46 |
|         | AOBLSS                                 | 9-47 |
|         | B                                      | 9-48 |
|         | BB                                     | 9-50 |
|         | BB                                     | 9-51 |
|         | BB                                     | 9-52 |
|         | BLB                                    | 9-53 |
|         | BR                                     | 9-54 |
|         | BSB                                    | 9-55 |
|         | CASE                                   | 9-56 |
|         | JMP                                    | 9-58 |
|         | JSB                                    | 9-59 |
|         | RSB                                    | 9-60 |
|         | SOBGEQ                                 | 9-61 |
|         | SOBGTR                                 | 9-62 |
| 9.2.5   | Procedure Call Instructions            | 9-63 |
|         | CALLG                                  | 9-65 |
|         | CALLS                                  | 9-67 |
|         | RET                                    | 9-69 |
| 9.2.6   | Miscellaneous Instructions             | 9-70 |
|         | BICPSW                                 | 9-71 |
|         | BISPSW                                 | 9-72 |
|         | BPT                                    | 9-73 |
|         | HALT                                   | 9-74 |
|         | INDEX                                  | 9-75 |
|         | MOVPSL                                 | 9-77 |
|         | NOP                                    | 9-78 |
|         | POPR                                   | 9-79 |
|         | PUSHR                                  | 9-80 |
|         | XFC                                    | 9-81 |
| 9.2.7   | Queue Instructions                     | 9-82 |
| 9.2.7.1 | Absolute Queues                        | 9-82 |
| 9.2.7.2 | Self-Relative Queues                   | 9-85 |
| 9.2.7.3 | Instruction Descriptions               | 9-88 |
|         | INSQHI                                 | 9-89 |
|         | INSQTI                                 | 9-91 |
|         | INSQUE                                 | 9-93 |
|         | REMQHI                                 | 9-95 |

|          |  |       |
|----------|--|-------|
|          | REMQTI .....                                     | 9-97  |
|          | REMQUE .....                                     | 9-99  |
| 9.2.8    | <b>Floating-Point Instructions</b> .....         | 9-101 |
| 9.2.8.1  | <b>Introduction</b> .....                        | 9-101 |
| 9.2.8.2  | <b>Overview of the Instruction Set</b> .....     | 9-102 |
| 9.2.8.3  | <b>Accuracy</b> .....                            | 9-103 |
| 9.2.8.4  | <b>Instruction Descriptions</b> .....            | 9-104 |
|          | ADD .....  | 9-106 |
|          | CLR .....  | 9-107 |
|          | CMP .....  | 9-108 |
|          | CVT .....  | 9-109 |
|          | DIV .....  | 9-111 |
|          | EMOD .....                                       | 9-113 |
|          | MNEG .....                                       | 9-115 |
|          | MOV .....  | 9-116 |
|          | MUL .....  | 9-117 |
|          | POLY .....                                       | 9-118 |
|          | SUB .....  | 9-121 |
|          | TST .....  | 9-123 |
| 9.2.9    | <b>Character String Instructions</b> .....       | 9-124 |
|          | CMPC .....                                       | 9-126 |
|          | LOCC .....                                       | 9-128 |
|          | MATCHC .....                                     | 9-129 |
|          | MOVC .....                                       | 9-130 |
|          | MOVTC .....                                      | 9-132 |
|          | MOVTUC .....                                     | 9-134 |
|          | SCANC .....                                      | 9-136 |
|          | SKPC .....                                       | 9-137 |
|          | SPANC .....                                      | 9-138 |
| 9.2.10   | <b>Cyclic Redundancy Check Instruction</b> ..... | 9-139 |
|          | CRC .....  | 9-140 |
| 9.2.11   | <b>Decimal String Instructions</b> .....         | 9-142 |
| 9.2.11.1 | <b>Decimal Overflow</b> .....                    | 9-143 |
| 9.2.11.2 | <b>Zero Numbers</b> .....                        | 9-143 |
| 9.2.11.3 | <b>Reserved Operand Exception</b> .....          | 9-143 |
| 9.2.11.4 | <b>UNPREDICTABLE Results</b> .....               | 9-143 |
| 9.2.11.5 | <b>Packed Decimal Operations</b> .....           | 9-143 |
| 9.2.11.6 | <b>Zero-Length Decimal Strings</b> .....         | 9-144 |
| 9.2.11.7 | <b>Instruction Descriptions</b> .....            | 9-144 |
|          | ADDP .....                                       | 9-146 |
|          | ASHP .....                                       | 9-148 |
|          | CMPP .....                                       | 9-150 |
|          | CVTLP .....                                      | 9-151 |
|          | CVTPL .....                                      | 9-152 |
|          | CVTPS .....                                      | 9-153 |
|          | CVTPT .....                                      | 9-155 |
|          | CVTSP .....                                      | 9-157 |
|          | CVTTP .....                                      | 9-159 |
|          | DIVP .....                                       | 9-161 |

|        |  |       |
|--------|--|-------|
|        | MOVP .....   | 9-163 |
|        | MULP .....   | 9-164 |
|        | SUBP .....   | 9-165 |
| 9.2.12 | The EDITPC Instruction and Its Pattern Operators ..... | 9-167 |
|        | EDITPC .....   | 9-168 |
|        | EO\$ADJUST_INPUT .....                                 | 9-172 |
|        | EO\$BLANK_ZERO .....                                   | 9-173 |
|        | EO\$END .....  | 9-174 |
|        | EO\$END_FLOAT .....                                    | 9-175 |
|        | EO\$FILL .....   | 9-176 |
|        | EO\$FLOAT .....  | 9-177 |
|        | EO\$INSERT .....                                       | 9-178 |
|        | EO\$LOAD_ .....  | 9-179 |
|        | EO\$MOVE .....   | 9-180 |
|        | EO\$REPLACE_SIGN .....                                 | 9-181 |
|        | EO\$_SIGNIF .....                                      | 9-182 |
|        | EO\$STORE_SIGN .....                                   | 9-183 |
| 9.2.13 | Other VAX Instructions .....                           | 9-184 |
|        | PROBE <sub>x</sub> .....                               | 9-185 |
|        | CHM .....  | 9-187 |
|        | REI .....  | 9-189 |
|        | LDPCTX .....   | 9-191 |
|        | SVPCTX .....   | 9-193 |
|        | MTPR .....   | 9-194 |
|        | MFPR .....   | 9-195 |
|        | BUG .....  | 9-196 |

## 10 VAX Vector Architecture

|          |   |       |
|----------|---|-------|
| 10.1     | Introduction to VAX Vector Architecture ..... | 10-1  |
| 10.2     | VAX Vector Architecture Registers .....       | 10-1  |
| 10.2.1   | Vector Registers .....                        | 10-1  |
| 10.2.2   | Vector Control Registers .....                | 10-2  |
| 10.2.3   | Internal Processor Registers .....            | 10-3  |
| 10.3     | Vector Instruction Formats .....              | 10-8  |
| 10.3.1   | Masked Operations .....                       | 10-9  |
| 10.3.2   | Exception Enable Bit .....                    | 10-10 |
| 10.3.3   | Modify Intent Bit .....                       | 10-10 |
| 10.3.4   | Register Specifier Fields .....               | 10-10 |
| 10.3.5   | Vector Control Word Formats .....             | 10-10 |
| 10.3.6   | Restrictions on Operand Specifier Usage ..... | 10-13 |
| 10.3.7   | VAX Condition Codes .....                     | 10-14 |
| 10.3.8   | Illegal Vector Opcodes .....                  | 10-14 |
| 10.4     | Assembler Notation .....                      | 10-14 |
| 10.5     | Execution Model .....                         | 10-15 |
| 10.5.1   | Access Mode Restrictions .....                | 10-16 |
| 10.5.2   | Scalar Context Switching .....                | 10-17 |
| 10.5.3   | Overlapped Instruction Execution .....        | 10-18 |
| 10.5.3.1 | Vector Chaining .....                         | 10-18 |
| 10.5.3.2 | Register Conflict .....                       | 10-20 |
| 10.5.3.3 | Dependencies Among Vector Results .....       | 10-20 |

|          |  |       |
|----------|--|-------|
| 10.6     | Vector Processor Exceptions . . . . .                                    | 10-24 |
| 10.6.1   | Vector Memory Management Exception Handling . . . . .                    | 10-25 |
| 10.6.2   | Vector Arithmetic Exceptions . . . . .                                   | 10-26 |
| 10.6.3   | Vector Processor Disabled . . . . .                                      | 10-27 |
| 10.6.4   | Handling Disabled Faults and Vector Context Switching . . . . .          | 10-28 |
| 10.6.5   | MFVP Exception Reporting Examples . . . . .                              | 10-30 |
| 10.7     | Synchronization . . . . .  | 10-33 |
| 10.7.1   | Scalar/Vector Instruction Synchronization (SYNC) . . . . .               | 10-33 |
| 10.7.2   | Scalar/Vector Memory Synchronization . . . . .                           | 10-34 |
| 10.7.2.1 | Memory Instruction Synchronization (MSYNC) . . . . .                     | 10-34 |
| 10.7.2.2 | Memory Activity Completion Synchronization (VMAC) . . . . .              | 10-35 |
| 10.7.3   | Other Synchronization Between the Scalar and Vector Processors . . . . . | 10-36 |
| 10.7.4   | Memory Synchronization Within the Vector Processor (VSYNC) . . . . .     | 10-36 |
| 10.7.5   | Required Use of Memory Synchronization Instructions . . . . .            | 10-37 |
| 10.7.5.1 | When VSYNC Is Not Required . . . . .                                     | 10-39 |
| 10.8     | Memory Management . . . . .  | 10-41 |
| 10.9     | Hardware Errors . . . . .  | 10-42 |
| 10.10    | Vector Memory Access Instructions . . . . .                              | 10-43 |
| 10.10.1  | Alignment Considerations . . . . .                                       | 10-43 |
| 10.10.2  | Stride Considerations . . . . .  | 10-43 |
| 10.10.3  | Context of Address Specifiers . . . . .                                  | 10-43 |
| 10.10.4  | Access Mode . . . . .  | 10-44 |
| 10.10.5  | Memory Instructions . . . . .  | 10-44 |
|          | VLD . . . . .  | 10-45 |
|          | VGATH . . . . .  | 10-47 |
|          | VST . . . . .  | 10-49 |
|          | VSCAT . . . . .  | 10-51 |
| 10.11    | Vector Integer Instructions . . . . .                                    | 10-52 |
|          | VADDL . . . . .  | 10-53 |
|          | VCMPL . . . . .  | 10-54 |
|          | VMULL . . . . .  | 10-56 |
|          | VSUBL . . . . .  | 10-58 |
| 10.12    | Vector Logical and Shift Instructions . . . . .                          | 10-59 |
|          | VBIC, VBIS, and VXOR . . . . .   | 10-60 |
|          | VSL . . . . .  | 10-62 |
| 10.13    | Vector Floating-Point Instructions . . . . .                             | 10-63 |
| 10.13.1  | Vector Floating-Point Exception Conditions . . . . .                     | 10-63 |
| 10.13.2  | Floating-Point Instructions . . . . .                                    | 10-64 |
|          | VADD . . . . .   | 10-65 |
|          | VCMP . . . . .   | 10-67 |
|          | VVCVT . . . . .  | 10-70 |
|          | VDIV . . . . .   | 10-72 |
|          | VMUL . . . . .   | 10-74 |
|          | VSUB . . . . .   | 10-76 |
| 10.14    | Vector Edit Instructions . . . . .                                       | 10-77 |
|          | VMERGE . . . . .   | 10-78 |
|          | IOTA . . . . .   | 10-79 |
| 10.15    | Miscellaneous Instructions . . . . .                                     | 10-80 |
|          | MFVP . . . . .   | 10-81 |
|          | MTVP . . . . .   | 10-83 |
|          | VSYNC . . . . .  | 10-84 |

## A ASCII Character Set

## B Hexadecimal/Decimal Conversion

|     |                                  |     |
|-----|----------------------------------|-----|
| B.1 | Hexadecimal to Decimal . . . . . | B-1 |
| B.2 | Decimal to Hexadecimal . . . . . | B-2 |
| B.3 | Powers of 2 and 16 . . . . .     | B-2 |

## C VAX MACRO Assembler Directives and Language Summary

|       |                                  |     |
|-------|----------------------------------|-----|
| C.1   | Assembler Directives . . . . .   | C-1 |
| C.2   | Special Characters . . . . .     | C-5 |
| C.3   | Operators . . . . .              | C-6 |
| C.3.1 | Unary Operators . . . . .        | C-7 |
| C.3.2 | Binary Operators . . . . .       | C-7 |
| C.3.3 | Macro String Operators . . . . . | C-8 |
| C.4   | Addressing Modes . . . . .       | C-9 |

## D Permanent Symbol Table Defined for Use with VAX MACRO

## E Exceptions That May Occur During Instruction Execution

|        |   |     |
|--------|---|-----|
| E.1    | Arithmetic Traps and Faults . . . . .                               | E-1 |
| E.1.1  | Integer Overflow Trap . . . . .                                     | E-2 |
| E.1.2  | Integer Divide-by-Zero Trap . . . . .                               | E-2 |
| E.1.3  | Floating Overflow Trap . . . . .                                    | E-2 |
| E.1.4  | Divide-by-Zero Trap . . . . .                                       | E-2 |
| E.1.5  | Floating Underflow Trap . . . . .                                   | E-2 |
| E.1.6  | Decimal String Overflow Trap . . . . .                              | E-3 |
| E.1.7  | Subscript-Range Trap . . . . .                                      | E-3 |
| E.1.8  | Floating Overflow Fault . . . . .                                   | E-3 |
| E.1.9  | Divide-by-Zero Floating Fault . . . . .                             | E-3 |
| E.1.10 | Floating Underflow Fault . . . . .                                  | E-3 |
| E.2    | Memory Management Exceptions . . . . .                              | E-3 |
| E.2.1  | Access Control Violation Fault . . . . .                            | E-3 |
| E.2.2  | Translation Not Valid Fault . . . . .                               | E-4 |
| E.3    | Exceptions Detected During Operand Reference . . . . .              | E-4 |
| E.3.1  | Reserved Addressing Mode Fault . . . . .                            | E-4 |
| E.3.2  | Reserved Operand Exception . . . . .                                | E-4 |
| E.4    | Exceptions Occurring as the Consequence of an Instruction . . . . . | E-5 |
| E.4.1  | Reserved or Privileged Instruction Fault . . . . .                  | E-5 |
| E.4.2  | Operand Reserved to Customers Fault . . . . .                       | E-5 |
| E.4.3  | Instruction Emulation Exceptions . . . . .                          | E-6 |
| E.4.4  | Compatibility Mode Exception . . . . .                              | E-6 |
| E.4.5  | Change Mode Trap . . . . .  | E-7 |
| E.4.6  | Breakpoint Fault . . . . .  | E-7 |
| E.5    | Trace Fault . . . . .   | E-7 |
| E.5.1  | Trace Operation When Entering a Change Mode Instruction . . . . .   | E-8 |
| E.5.2  | Trace Operation Upon Return From Interrupt . . . . .                | E-8 |
| E.5.3  | Trace Operation After a BISPSW Instruction . . . . .                | E-8 |
| E.5.4  | Trace Operation After a CALLS or CALLG Instruction . . . . .        | E-8 |
| E.6    | Serious System Failures . . . . .                                   | E-9 |
| E.6.1  | Kernel Stack Not Valid Abort . . . . .                              | E-9 |
| E.6.2  | Interrupt Stack Not Valid Halt . . . . .                            | E-9 |

|       |                                   |     |
|-------|-----------------------------------|-----|
| E.6.3 | Machine Check Exception . . . . . | E-9 |
|-------|-----------------------------------|-----|

## Index

### Figures

|       |   |       |
|-------|---|-------|
| 6-1   | Using Transfer Vectors . . . . .  | 6-96  |
| 10-1  | Vector Register . . . . .   | 10-2  |
| 10-2  | Vector Length Register (VLR) . . . . .  | 10-2  |
| 10-3  | Vector Mask Register (VMR) . . . . .  | 10-3  |
| 10-4  | Vector Count Register (VCR) . . . . .   | 10-3  |
| 10-5  | Vector Processor Status Register (VPSR) . . . . .                               | 10-3  |
| 10-6  | Vector Arithmetic Exception Register (VAER) . . . . .                           | 10-6  |
| 10-7  | Vector Memory Activity Check (VMAC) Register . . . . .                          | 10-6  |
| 10-8  | Vector Translation Buffer Invalidate All (VTBIA) Register . . . . .             | 10-7  |
| 10-9  | Vector State Address Register (VSAR) . . . . .                                  | 10-7  |
| 10-10 | Vector Control Word Operand (cntrl) . . . . .                                   | 10-8  |
| 10-11 | Vector Control Word Format . . . . .  | 10-12 |
| 10-12 | Memory Management Fault Stack Frame (as Sent by the Vector Processor) . . . . . | 10-25 |
| 10-13 | Encoding of the Reserved Operand . . . . .                                      | 10-64 |
| E-1   | Compatibility Mode Exception Stack Frame . . . . .                              | E-6   |

### Tables

|     |  |      |
|-----|--|------|
| 3-1 | Special Characters Used in VAX MACRO Statements . . . . .                            | 3-1  |
| 3-2 | Separating Characters in VAX MACRO Statements . . . . .                              | 3-2  |
| 3-3 | Unary Operators . . . . .  | 3-10 |
| 3-4 | Binary Operators . . . . .   | 3-14 |
| 5-1 | Addressing Modes . . . . .   | 5-2  |
| 5-2 | Floating-Point Literals Expressed as Decimal Numbers . . . . .                       | 5-9  |
| 5-3 | Floating-Point Literals Expressed as Rational Numbers . . . . .                      | 5-9  |
| 5-4 | Index Mode Addressing . . . . .  | 5-16 |
| 6-1 | Summary of General Assembler Directives . . . . .                                    | 6-1  |
| 6-2 | Summary of Macro Directives . . . . .  | 6-2  |
| 6-3 | .ENABLE and .DISABLE Symbolic Arguments . . . . .                                    | 6-22 |
| 6-4 | Condition Tests for Conditional Assembly Directives . . . . .                        | 6-41 |
| 6-5 | Operand Descriptors . . . . .  | 6-72 |
| 6-6 | Program Section Attributes . . . . .   | 6-77 |
| 6-7 | Default Program Section Attributes . . . . .   | 6-79 |
| 6-8 | .SHOW and .NOSHOW Symbolic Arguments . . . . .                                       | 6-88 |
| 8-1 | Representation of Least-Significant Digit and Sign in Zoned Numeric Format . . . . . | 8-9  |
| 8-2 | Representation of Least-Significant Digit and Sign in Overpunch Format . . . . .     | 8-10 |
| 8-3 | Floating-Point Literals Expressed as Decimal Numbers . . . . .                       | 8-22 |
| 8-4 | Floating-Point Literals Expressed as Rational Numbers . . . . .                      | 8-23 |

|       |   |       |
|-------|---|-------|
| 8-5   | General Register Addressing . . . . .   | 8-25  |
| 8-6   | Program Counter Addressing . . . . .  | 8-26  |
| 9-1   | Summary of EDITPC Pattern Operators . . . . .   | 9-170 |
| 9-2   | EDITPC Pattern Operator Encoding . . . . .  | 9-171 |
| 10-1  | Description of the Vector Processor Status Register (VPSR) . . . . .  | 10-4  |
| 10-2  | Possible VPSR<3:0> Settings for MTPR . . . . .  | 10-5  |
| 10-3  | State of the Vector Processor . . . . .   | 10-5  |
| 10-4  | VAER Exception Condition Summary Word Encoding . . . . .  | 10-6  |
| 10-5  | IPR Assignments . . . . .   | 10-8  |
| 10-6  | Description of the Vector Control Word Operand . . . . .  | 10-9  |
| 10-7  | Dependencies for Vector Operate Instructions . . . . .  | 10-21 |
| 10-8  | Dependencies for Vector Load and Gather Instructions . . . . .  | 10-22 |
| 10-9  | Dependencies for Vector Store and Scatter Instructions . . . . .  | 10-22 |
| 10-10 | Dependencies for Vector Compare Instructions . . . . .  | 10-23 |
| 10-11 | Dependencies for Vector MERGE Instructions . . . . .  | 10-23 |
| 10-12 | Dependencies for IOTA Instruction . . . . .   | 10-23 |
| 10-13 | Dependencies for MFVP Instructions . . . . .  | 10-24 |
| 10-14 | Miscellaneous Dependencies . . . . .  | 10-24 |
| 10-15 | Possible Pairs of Read and Write Operations When Scalar/Vector<br>Memory Synchronization (M) or VSYNC (V) Is Required Between<br>Instructions That Reference the Same Memory Location . . . . . | 10-39 |
| 10-16 | Encoding of the Exception Condition Type (ETYPE) . . . . .  | 10-64 |
| C-1   | Assembler Directives . . . . .  | C-1   |
| C-2   | Special Characters Used in VAX MACRO Statements . . . . .   | C-6   |
| C-3   | Summary of Unary Operators . . . . .  | C-7   |
| C-4   | Summary of Binary Operators . . . . .   | C-7   |
| C-5   | Macro String Operators . . . . .  | C-8   |
| C-6   | Summary of Addressing Modes . . . . .   | C-9   |
| D-1   | Opcodes (Alphabetic Order) and Functions . . . . .  | D-1   |
| D-2   | One_Byte Opcodes (Numeric Order) . . . . .  | D-11  |
| D-3   | Two_Byte Opcodes (Numeric Order) . . . . .  | D-15  |
| E-1   | Arithmetic Exception Type Codes . . . . .   | E-1   |
| E-2   | Compatibility Mode Exception Type Codes . . . . .   | E-6   |

## Intended Audience

This manual is intended for all programmers writing VAX MACRO programs. You should be familiar with assembly language programming, the VAX instruction set, and the OpenVMS operating system before reading this manual.

## Document Structure

This manual is divided into two parts, each of which is subdivided into several chapters.

Part I describes the VAX MACRO language.

- Chapter 1 introduces the features of the VAX MACRO language.
- Chapter 2 describes the format used in VAX MACRO source statements.
- Chapter 3 describes the following components of VAX MACRO source statements:
  - Character set
  - Numbers
  - Symbols
  - Local labels
  - Terms and expressions
  - Unary and binary operators
  - Direct assignment statements
  - Current location counter
- Chapter 4 describes the arguments and string operators used with macros.
- Chapter 5 summarizes and gives examples of using the VAX MACRO addressing modes.
- Chapter 6 describes the VAX MACRO general assembler directives and the directives used in defining and expanding macros.

Part II describes the VAX data types, the instruction and addressing mode formats, and the instruction set.

- Chapter 7 summarizes the terminology and conventions used in the descriptions in Part II.
- Chapter 8 describes the basic VAX architecture, including the following:
  - Address space
  - Data types

- Processor status longword
- Permanent exception enables
- Instruction and addressing mode formats
- Chapter 9 describes the native-mode instruction set. The instructions are divided into groups according to their function and are listed alphabetically within each group.
- Chapter 10 describes the extension to the VAX architecture for integrated vector processing.

This manual also contains the following five appendixes:

- Appendix A lists the ASCII character set used in VAX MACRO programs.
- Appendix B gives rules for hexadecimal/decimal conversion.
- Appendix C summarizes the general assembler and macro directives (in alphabetical order), special characters, unary operators, binary operators, macro string operators, and addressing modes.
- Appendix D lists the permanent symbols (instruction set) defined for use with VAX MACRO.
- Appendix E describes the exceptions (traps and faults) that may occur during instruction execution.

## Related Documents

The following documents are relevant to VAX MACRO programming:

- *VAX Architecture Reference Manual*
- *OpenVMS DCL Dictionary*
- The descriptions of the VMS Linker and Symbolic Debugger in:
  - *OpenVMS Linker Utility Manual*
  - *OpenVMS Debugger Manual*
- *OpenVMS Programming Concepts Manual*

For additional information about OpenVMS products and services, access the following World Wide Web address:

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## Conventions

The following conventions are used in this manual:

|  |   |
|--|---|
| Ctrl/ <i>x</i>   | A sequence such as Ctrl/ <i>x</i> indicates that you must hold down the key labeled Ctrl while you press another key or a pointing device button.   |
| PF1 <i>x</i>   | A sequence such as PF1 <i>x</i> indicates that you must first press and release the key labeled PF1 and then press and release another key or a pointing device button.   |
| <span style="border: 1px solid black; padding: 2px;">Return</span> | <p>In examples, a key name enclosed in a box indicates that you press a key on the keyboard. (In text, a key name is not enclosed in a box.)</p> <p>In the HTML version of this document, this convention appears as brackets, rather than a box.</p>   |
| ...  | <p>A horizontal ellipsis in examples indicates one of the following possibilities:</p> <ul style="list-style-type: none"><li>• Additional optional arguments in a statement have been omitted.</li><li>• The preceding item or items can be repeated one or more times.</li><li>• Additional parameters, values, or other information can be entered.</li></ul> |
| .  | A vertical ellipsis indicates the omission of items from a code example or command format; the items are omitted because they are not important to the topic being discussed.   |
| ( )  | In command format descriptions, parentheses indicate that you must enclose choices in parentheses if you specify more than one.   |
| [ ]  | <p>In command format descriptions, brackets indicate optional choices. You can choose one or more items or no items. Do not type the brackets on the command line. However, you must include the brackets in the syntax for OpenVMS directory specifications and for a substring specification in an assignment statement.</p>                                  |
|  | In command format descriptions, vertical bars separate choices within brackets or braces. Within brackets, the choices are optional; within braces, at least one choice is required. Do not type the vertical bars on the command line.   |
| { }  | In command format descriptions, braces indicate required choices; you must choose at least one of the items listed. Do not type the braces on the command line.   |
| <b>bold text</b>   | This typeface represents the introduction of a new term. It also represents the name of an argument, an attribute, or a reason.   |

|                    |  |
|--------------------|--|
| <i>italic text</i> | Italic text indicates important information, complete titles of manuals, or variables. Variables include information that varies in system output (Internal error <i>number</i> ), in command lines (/PRODUCER= <i>name</i> ), and in command parameters in text (where <i>dd</i> represents the predefined code for the device type).     |
| UPPERCASE TEXT     | Uppercase text indicates a command, the name of a routine, the name of a file, or the abbreviation for a system privilege.   |
| Monospace text     | Monospace type indicates code examples and interactive screen displays.<br><br>In the C programming language, monospace type in text identifies the following elements: keywords, the names of independently compiled external functions and files, syntax summaries, and references to variables or identifiers introduced in an example. |
| -                  | A hyphen at the end of a command format description, command line, or code line indicates that the command or statement continues on the following line.   |
| numbers            | All numbers in text are assumed to be decimal unless otherwise noted. Nondecimal radices—binary, octal, or hexadecimal—are explicitly indicated.   |

---

# VAX MACRO Language

Part I provides an overview of the features of the VAX MACRO language. It includes an introduction to the structure and components of VAX MACRO source statements. Part I also contains a detailed discussion of the VAX MACRO addressing modes, general assembler directives, and macro directives.



---

## Introduction

VAX MACRO is an assembly language for programming VAX computers using the OpenVMS operating system. Source programs written in VAX MACRO are translated into object (or binary) code by the VAX MACRO assembler, which produces an object module and, optionally, a listing file. The features of the language are introduced in this chapter.

VAX MACRO source programs consist of a sequence of source statements. These source statements may be any of the following:

- VAX native-mode instructions
- Direct assignment statements
- Assembler directives

**Instructions** manipulate data. They perform such functions as addition, data conversion, and transfer of control. Instructions are usually followed in the source statement by operands, which can be any kind of data needed for the operation of the instruction. The VAX instruction set is summarized in Appendix D of this volume and is described in detail in Chapter 9. **Direct assignment statements** equate symbols to values. **Assembler directives** guide the assembly process and provide tools for using the instructions. There are two classes of assembler directives: general assembler directives and macro directives.

General assembler directives can be used to perform the following operations:

- Store data or reserve memory for data storage
- Control the alignment of parts of the program in memory
- Specify the methods of accessing the sections of memory in which the program will be stored
- Specify the entry point of the program or a part of the program
- Specify the way in which symbols will be referenced
- Specify that a part of the program is to be assembled only under certain conditions
- Control the format and content of the listing file
- Display informational messages
- Control the assembler options that are used to interpret the source program
- Define new opcodes

Macro directives are used to define macros and repeat blocks. They allow you to perform the following operations:

- Repeat identical or similar sequences of source statements throughout a program without rewriting those sequences

## Introduction

- Use string operators to manipulate and test the contents of source statements
- Use of macros and repeat blocks helps minimize programmer errors and speeds the debugging process.

---

## VAX MACRO Source Statement Format

A source program consists of a sequence of source statements that the assembler interprets and processes, one at a time, generating object code or performing a specific assembly-time process. A source statement can occupy one source line or can extend onto several source lines. Each source line can be up to 132 characters long; however, to ensure that the source line fits (with its binary expansion) on one line in the listing file, no line should exceed 80 characters.

VAX MACRO statements can consist of up to four fields, as follows:

- Label field—symbolically defines a location in a program.
- Operator field—specifies the action to be performed by the statement; can be an instruction, an assembler directive, or a macro call.
- Operand field—contains the instruction operands, the assembler directive arguments, or the macro arguments.
- Comment field—contains a comment that explains the meaning of the statement; does not affect program execution.

The label field and the comment field are optional. The label field ends with a colon (: ) and the comment field begins with a semicolon (;). The operand field must conform to the format of the instruction, directive, or macro specified in the operator field.

Although statement fields can be separated by either a space or a tab (see Table 3-2), formatting statements with the tab character is recommended for consistency and clarity and is a Compaq convention.

| Field    | Begins in Column | Tab Characters to Reach Column |
|----------|------------------|--------------------------------|
| Label    | 1                | 0                              |
| Operator | 9                | 1                              |
| Operand  | 17               | 2                              |
| Comment  | 41               | 5                              |

For example:

```

        .TITLE  ROUT1
        .ENTRY  START, ^M<>           ; Beginning of routine
        CLRL   R0                      ; Clear register
LABT:   SUBL3  #10,4(AP),R2           ; Subtract 10
LAB2:   BRB   CONT                    ; Branch to another routine

```

Continue a single statement on several lines by using a hyphen (-) as the last nonblank character before the comment field, or at the end of a line (when there is no comment). For example:

## VAX MACRO Source Statement Format

```
LAB1:  MOVAL  W^BOO$AL_VECTOR,-      ; Save boot driver
        RPB$L_IOVEC(R7)
```

VAX MACRO treats the preceding statement as equivalent to the following statement:

```
LAB1:  MOVAL  W^BOO$AL_VECTOR,RPB$L_IOVEC(R7) ; Save boot driver
```

A statement can be continued at any point. Do not continue permanent and user-defined symbol names on two lines. If a symbol name is continued and the first character on the second line is a tab or a blank, the symbol name is terminated at that character. Section 3.3 describes symbols in detail.

Note that when a statement occurs in a macro definition (see Chapter 4 and Chapter 6), the statement cannot contain more than 1000 characters.

Blank lines are legal, but they have no significance in the source program except that they terminate a continued line.

The following sections describe each of the statement fields in detail.

### 2.1 Label Field

A label is a user-defined symbol that identifies a location in the program. The symbol is assigned a value equal to the location counter where the label occurs. The user-defined symbol name can be up to 31 characters long and can contain any alphanumeric character and the underscore (`_`), dollar sign (`$`), and period (`.`) characters. See Section 3.3.2 for a description of the rules for forming user-defined symbol names in more detail.

If a statement contains a label, the label must be in the first field on the line.

A label is terminated by a colon (`:`) or a double colon (`::`). A single colon indicates that the label is defined only for the current module (an internal symbol). A double colon indicates that the label is globally defined; that is, the label can be referenced by other object modules.

Once a label is defined, it cannot be redefined during the source program. If a label is defined more than once, VAX MACRO displays an error message when the label is defined and again when it is referenced.

If a label extends past column 7, place it on a line by itself so that the following operator field can start in column 9 of the next line.

The following example illustrates some of the ways you can define labels:

```
EXP:    .BLKL  50      ; Table stores expected values
DATA::  .BLKW  25      ; Data table accessed by store
        ; routine in another module
EVAL:   CLRL   R0      ; Routine evaluates expressions
ERROR_IN_ARG:
        INCL   R0      ; increment error count
TEST::  MOVO   EXP,R1  ; This tests routine
        ; referenced externally
TEST1:  BRW    EXIT   ; Go to exit routine
```

The label field is also used for the symbol in a direct assignment statement (see Section 3.8).

## 2.2 Operator Field

The operator field specifies the action to be performed by the statement. This field can contain an instruction, an assembler directive, or a macro call.

When the operator is an instruction, VAX MACRO generates the binary code for that instruction in the object module. The binary codes are listed in Appendix D; the instruction set is described in Chapter 9. When the operator is a directive, VAX MACRO performs certain control actions or processing operations during source program assembly. The assembler directives are described in Chapter 6. When the operator is a macro call, VAX MACRO expands the macro. Macro calls are described in Chapter 4 and in Chapter 6 (.MACRO directive).

Use either a space or a tab character to terminate the operator field; however, the tab is the recommended termination character.

## 2.3 Operand Field

The operand field can contain operands for instructions or arguments for either assembler directives or macro calls.

Operands for instructions identify the memory locations or the registers that are used by the machine operation. These operands specify the addressing mode for the instruction, as described in Chapter 5. The operand field for a specific instruction must contain the number of operands required by that instruction. See Chapter 9 for descriptions of the instructions and their operands.

Arguments for a directive must meet the format requirements of that directive. Chapter 6 describes the directives and the format of their arguments.

Operands for a macro must meet the requirements specified in the macro definition. See the description of the .MACRO directive in Chapter 6.

If two or more operands are specified, they must be separated by commas (,). VAX MACRO also allows a space or tab to be used as a separator for arguments to any directive that does not accept expressions (see Section 3.5 for a discussion of expressions). However, a comma is required to separate operands for instructions and for directives that accept expressions as arguments.

The semicolon that starts the comment field terminates the operand field. If a line does not have a comment field, the operand field is terminated by the end of the line.

## 2.4 Comment Field

The comment field contains text that explains the function of the statement. Every line of code should have a comment. Comments do not affect assembly processing or program execution. You can cause user-written messages to be displayed during assembly by the .ERROR, .PRINT, and .WARN directives (see descriptions in Chapter 6).

The comment field must be preceded by a semicolon; it is terminated by the end of the line. The comment field can contain any printable ASCII character (see Appendix A).

To continue a lengthy comment to the next line, write the comment on the next line and precede it with another semicolon. If a comment does not fit on one line, it can be continued on the next, but the continuation must be preceded by another semicolon. A comment can appear on a line by itself.

## VAX MACRO Source Statement Format

### 2.4 Comment Field

Write the text of a comment to convey the meaning rather than the action of the statement. The instruction `MOVAL BUF_PTR_1,R7`, for example, should have a comment such as "Get pointer to first buffer," not "Move address of `BUF_PTR_1` to `R7`."

For example:

```
MOVAL  STRING_DES_1,R0 ; Get address of string
                        ; descriptor
MOVZWL (R0),R1         ; Get length of string
MOVL   4(R0),R0        ; Get address of string
```

---

## Components of MACRO Source Statements

This chapter describes the following components of VAX MACRO source statements:

- Character set
- Numbers
- Symbols
- Local labels
- Terms and expressions
- Unary and binary operators
- Direct assignment statements
- Current location counter

### 3.1 Character Set

The following characters can be used in VAX MACRO source statements:

- The letters of the alphabet, A to Z, uppercase and lowercase. Note that the assembler considers lowercase letters equivalent to uppercase letters except when they appear in ASCII strings.
- The digits 0 to 9.
- The special characters listed in Table 3–1.

**Table 3–1 Special Characters Used in VAX MACRO Statements**

| Character | Character Name | Function   |
|-----------|----------------|--|
| _         | Underscore     | Character in symbol names  |
| \$        | Dollar sign    | Character in symbol names  |
| .         | Period         | Character in symbol names, current location counter, and decimal point |
| :         | Colon          | Label terminator   |
| =         | Equal sign     | Direct assignment operator and macro keyword argument terminator       |
|           | Tab            | Field terminator   |
|           | Space          | Field terminator   |
| #         | Number sign    | Immediate addressing mode indicator                                    |

(continued on next page)

## Components of MACRO Source Statements

### 3.1 Character Set

**Table 3–1 (Cont.) Special Characters Used in VAX MACRO Statements**

| Character | Character Name       | Function  |
|-----------|----------------------|---|
| @         | At sign              | Deferred addressing mode indicator and arithmetic shift operator  |
| ,         | Comma                | Field, operand, and item separator  |
| ;         | Semicolon            | Comment field indicator   |
| +         | Plus sign            | Autoincrement addressing mode indicator, unary plus operator, and arithmetic addition operator                                  |
| -         | Minus sign or hyphen | Autodecrement addressing mode indicator, unary minus operator, arithmetic subtraction operator, and line continuation indicator |
| *         | Asterisk             | Arithmetic multiplication operator  |
| /         | Slash                | Arithmetic division operator  |
| &         | Ampersand            | Logical AND operator  |
| !         | Exclamation point    | Logical inclusive OR operator point   |
| \         | Backslash            | Logical exclusive OR and numeric conversion indicator in macro arguments  |
| ^         | Circumflex           | Unary operators and macro argument delimiter  |
| [ ]       | Square brackets      | Index addressing mode and repeat count indicators   |
| ( )       | Parentheses          | Register deferred addressing mode indicators  |
| <>        | Angle brackets       | Argument or expression grouping delimiters  |
| ?         | Question mark        | Created local label indicator in macro arguments  |
| '         | Apostrophe           | Macro argument concatenation indicator  |
| %         | Percent sign         | Macro string operators  |

Table 3–2 defines the separating characters used in VAX MACRO.

**Table 3–2 Separating Characters in VAX MACRO Statements**

| Character                      | Character Name | Usage   |
|--------------------------------|----------------|---|
| <i>(space)</i><br><i>(tab)</i> | Space or tab   | Separator between statement fields. Spaces within expressions are ignored.  |
| ,                              | Comma          | Separator between symbolic arguments within the operand field. Multiple expressions in the operand field must be separated by commas. |

## 3.2 Numbers

Numbers can be integers, floating-point numbers, or packed decimal strings.

### 3.2.1 Integers

Integers can be used in any expression including expressions in operands and in direct assignment statements (Section 3.5 describes expressions).

#### Format

snn

#### s

An optional sign: plus sign (+) for positive numbers (the default) or minus sign (-) for negative numbers.

#### nn

A string of numeric characters that is legal for the current radix.

VAX MACRO interprets all integers in the source program as decimal unless the number is preceded by a radix control operator (see Section 3.6.1).

Integers must be in the range of -2,147,483,648 to +2,147,483,647 for signed data or in the range of 0 to 4,294,967,295 for unsigned data.

Negative numbers must be preceded by a minus sign; VAX MACRO translates such numbers into two's complement form. In positive numbers, the plus sign is optional.

### 3.2.2 Floating-Point Numbers

A floating-point number can be used in the `.F_FLOATING` (`.FLOAT`), `.D_FLOATING` (`.DOUBLE`), `.G_FLOATING`, and `.H_FLOATING` directives (described in Chapter 6) or as an operand in a floating-point instruction. A floating-point number cannot be used in an expression or with a unary or binary operator except the unary plus, unary minus, and unary floating-point operator, `^F` (`F_FLOATING`). Section 3.6 and Section 3.7 describe unary and binary operators.

A floating-point number can be specified with or without an exponent.

#### Formats

Floating-point number without exponent:

snn

snn.nn

snn.

Floating-point number with exponent:

snnEsnn

snn.nnEsnn

snn.Esnn

#### s

An optional sign.

#### nn

A string of decimal digits in the range of 0 to 9.

The decimal point can appear anywhere to the right of the first digit. Note that a floating-point number cannot start with a decimal point because VAX MACRO will treat the number as a user-defined symbol (see Section 3.3.2).

## Components of MACRO Source Statements

### 3.2 Numbers

Floating-point numbers can be single-precision (32-bit), double-precision (64-bit), or extended-precision (128-bit) quantities. The degree of precision is 7 digits for single-precision numbers, 16 digits for double-precision numbers, and 33 digits for extended-precision numbers.

The magnitude of a nonzero floating-point number cannot be smaller than approximately 0.29E-38 or greater than approximately 1.7E38.

Single-precision floating-point numbers can be rounded (by default) or truncated. The `.ENABLE` and `.DISABLE` directives (described in Chapter 6) control whether single-precision floating-point numbers are rounded or truncated. Double-precision and extended-precision floating-point numbers are always rounded.

Section 8.3.6, Section 8.3.7, Section 8.3.8, and Section 8.3.9 describe the internal format of floating-point numbers.

#### 3.2.3 Packed Decimal Strings

A packed decimal string can be used only in the `.PACKED` directive (described in Chapter 6).

##### Format

`snn`

`s`

An optional sign.

`nn`

A string containing up to 31 decimal digits in the range of 0 to 9.

A packed decimal string cannot have a decimal point or an exponent.

Section 8.3.14 describes the internal format of packed decimal strings.

### 3.3 Symbols

Three types of symbols can be used in VAX MACRO source programs: permanent symbols, user-defined symbols, and macro names.

#### 3.3.1 Permanent Symbols

Permanent symbols consist of instruction mnemonics (see Appendix D), VAX MACRO directives (see Chapter 6), and register names. You need not define instruction mnemonics and directives before you use them in the operator field of a VAX MACRO source statement. Also, you need not define register names before using them in the addressing modes (see Chapter 5).

Register names cannot be redefined; that is, a symbol that you define cannot be one of the register names contained in the following list. You can express the 16 general registers of the VAX processor in a source program only as follows:

| Register Name | Processor Register |
|---------------|--------------------|
| R0            | General register 0 |
| R1            | General register 1 |
| R2            | General register 2 |
| .             | .                  |

---

| Register Name | Processor Register   |
|---------------|--|
| .             | .  |
| .             | .  |
| R11           | General register 11  |
| R12 or AP     | General register 12 or argument pointer. If you use R12 as an argument pointer, the name AP is recommended; if you use R12 as a general register, the name R12 is recommended. |
| FP            | Frame pointer  |
| SP            | Stack pointer  |
| PC            | Program counter  |

---

Note that the symbols IV and DV are also permanent symbols and cannot be redefined. These symbols are used in the register mask to set the integer overflow trap (IV) and the decimal string overflow trap (DV). See Section 3.6.2.2 for an explanation of their uses.

### 3.3.2 User-Defined Symbols and Macro Names

You can use symbols that you define as labels or you can equate them to a specific value by a direct assignment statement (see Section 3.8). These symbols can also be used in any expression (see Section 3.5).

The following rules govern the creation of user-defined symbols:

- User-defined symbols can be composed of alphanumeric characters, underscores (`_`), dollar signs (`$`), and periods (`.`). Any other character terminates the symbol.
- The first character of a symbol must not be a number.
- The symbol must be no more than 31 characters long and must be unique.

In addition, by Compaq convention:

- The dollar sign (`$`) is reserved for names defined by Compaq. This convention ensures that a user-defined name (which does not have a dollar sign) will not conflict with a Compaq-defined name (which does have a dollar sign).
- Do not use the period (`.`) in any global symbol name (see Section 3.3.3) because languages, such as FORTRAN, do not allow periods in symbol names.

Macro names follow the same rules and conventions as user-defined symbols. (See the description of the `.MACRO` directive in Chapter 6 for more information on macro names.) User-defined symbols and macro names do not conflict; that is, the same name can be used for a user-defined symbol and a macro. To avoid confusion, give the symbols and macros that you define different names.

### 3.3.3 Determining Symbol Values

The value of a symbol depends on its use in the program. VAX MACRO uses a different method to determine the values of symbols in the operator field than it uses to determine the values of symbols in the operand field.

A symbol in the operator field can be either a permanent symbol or a macro name. VAX MACRO searches for a symbol definition in the following order:

1. Previously defined macro names
2. User-defined opcode (see the `.OPDEF` description in Chapter 6)

## Components of MACRO Source Statements

### 3.3 Symbols

3. Permanent symbols (instructions and directives)
4. Macro libraries

This search order allows permanent symbols to be redefined as macro names. If a symbol in the operator field is not defined as a macro or a permanent symbol, the assembler displays an error message.

A symbol in the operand field must be either a user-defined symbol or a register name.

User-defined symbols can be either local (internal) symbols or global (external) symbols. Whether symbols are local or global depends on their use in the source program.

A local symbol can be referenced only in the module in which it is defined. If local symbols with the same names are defined in different modules, the symbols are completely independent. The definition of a global symbol, however, can be referenced from any module in the program.

VAX MACRO treats all symbols that you define as local unless you explicitly declared them to be global by doing any one of the following:

- Use the double colon (::) in defining a label (see Section 2.1).
- Use the double equal sign (=) in a direct assignment statement (see Section 3.8).
- Use the .GLOBAL, .ENTRY, or .WEAK directive (see Chapter 6).

When your code references a symbol within the module in which it is defined, VAX MACRO considers the reference internal. When your code references a symbol within a module in which it is not defined, VAX MACRO considers the reference external (that is, the symbol is defined externally in another module). You can use the .DISABLE directive to make references to symbols not defined in the current module illegal. In this case, you must use the .EXTERNAL directive to specify that the reference is an external reference. See Chapter 6 for descriptions of the .DISABLE and .EXTERNAL directives.

### 3.4 Local Labels

Use local labels to identify addresses within a block of source code.

#### Format

nn\$

#### nn

A decimal integer in the range of 1 to 65535.

Use local labels in the same way as you use the symbol labels that you define, with the following differences:

- Local labels cannot be referenced outside the block of source code in which they appear.
- Local labels can be reused in another block of source code.
- Local labels do not appear in the symbol tables and thus cannot be accessed by the VAX Symbolic Debugger.
- Local labels cannot be used in the .END directive (see Chapter 6).

## Components of MACRO Source Statements

### 3.4 Local Labels

By convention, local labels are positioned like statement labels: left-justified in the source text. Although local labels can appear in the program in any order, by convention, the local labels in any block of source code should be in numeric order.

Local labels are useful as branch addresses when you use the address only within the block. You can use local labels to distinguish between addresses that are referenced only in a small block of code and addresses that are referenced elsewhere in the module. A disadvantage of local labels is that their numeric names cannot provide any indication of their purpose. Consequently, you should not use local labels to label sequences of statements that are logically unrelated; user-defined symbols should be used instead.

Compaq recommends that users create local labels only in the range of 1\$ to 29999\$ because the assembler automatically creates local labels in the range of 30000\$ to 65535\$ for use in macros (see Section 4.7).

The local label block in which a local label is valid is delimited by the following statements:

- A user-defined label
- A .PSECT directive (see Chapter 6)
- The .ENABLE and .DISABLE directives (see Chapter 6), which can extend a local label block beyond user-defined labels and .PSECT directives

A local label block is usually delimited by two user-defined labels. However, the .ENABLE LOCAL\_BLOCK directive starts a local block that is terminated only by one of the following:

- A second .ENABLE LOCAL\_BLOCK directive
- A .DISABLE LOCAL\_BLOCK directive followed by a user-defined label or a .PSECT directive

Although local label blocks can extend from one program section to another, Compaq recommends that local labels in one program section not be referenced from another program section. User-defined symbols should be used instead.

Local labels can be preserved for future reference with the context of the program section in which they are defined; see the descriptions of the .SAVE\_PSECT [LOCAL\_BLOCK] directive and the .RESTORE\_PSECT directive in Chapter 6.

An example showing the use of local labels follows:

```
RPSUB:  MOVL   AMOUNT,R0      ; Start local label block
10$:    SUBL2  DELTA,R0      ; Define local label 10$
        BGTR   10$          ; Conditional branch to local label
        ADDL2  DELTA,R0     ; Executed when R0 not > 0
COMP:   MOVL   MAX,R1       ; End previous local label
        CLRL   R2           ; block and start new one
10$:    CMPL   R0,R1        ; Define new local label 10$
        BGTR   20$          ; Conditional branch to local label
        SUBL   INCR,R0     ; Executed when R0 not > R1
        INCL   R2           ; . . .
        BRB   10$          ; Unconditional branch to local label
20$:    MOVL   R2,COUNT     ; Define local label
        BRW   TEST         ; Unconditional branch to user-defined label
```

## Components of MACRO Source Statements

### 3.4 Local Labels

```
      .ENABLE LOCAL_BLOCK      ; Start local label block that
ENTR1: POPR   #^M<R0,R1,R2>    ; will not be terminated
      ADDL3   R0,R1,R3        ; by a user-defined label
      BRB     10$             ; Branch to local label that appears
                                ; after a user-defined label
ENTR2:  SUBL2   R2,R3         ; Does not start a new local label block
10$:    SUBL2   R2,R3         ; Define local label
      BGTR    20$             ; Conditional branch to local label
      INCL    R0              ; Executed when R2 not > R3
      BRB     NEXT           ; Unconditional branch to user-defined label
20$:    DECL    R0           ; Define local label
      .DISABLE LOCAL_BLOCK    ; Directive followed by user-defined
NEXT:   CLRL    R4           ; label terminates local label block
```

### 3.5 Terms and Expressions

A term can be any of the following:

- A number
- A symbol
- The current location counter (see Section 3.9)
- A textual operator followed by text (see Section 3.6.2)
- Any of the previously noted items preceded by a unary operator (see Section 3.6)

VAX MACRO evaluates terms as longword (4-byte) values. If you use an undefined symbol as a term, the linker determines the value of the term. The current location counter (.) has the value of the location counter at the start of the current operand.

Expressions are combinations of terms joined by binary operators (see Section 3.7) and evaluated as longword (4-byte) values. VAX MACRO evaluates expressions from left to right with no operator precedence rules. However, angle brackets (<>) can be used to change the order of evaluation. Any part of an expression that is enclosed in angle brackets is first evaluated to a single value, which is then used in evaluating the complete expression. For example, the expressions  $A*B+C$  and  $A*<B+C>$  are different. In the first case, A and B are multiplied and then C added to the product. In the second case, B and C are added and the sum is multiplied by A. Angle brackets can also be used to apply a unary operator to an entire expression, such as  $-<A+B>$ .

If an arithmetic expression is continued on another line, the listing file will not show the continued line. For example:

```
.WORD <DATA1' $^XFF@8+-
      89>
```

You must use `/LIST/SHOW=EXPANSION` to show the continuation line.

VAX MACRO considers unary operators part of a term and thus, performs the action indicated by a unary operator before it performs the action indicated by any binary operator.

Expressions fall into three categories: relocatable, absolute, and external (global), as follows:

- An expression is relocatable if its value is fixed relative to the start of the program section in which it appears. The current location counter is relocatable in a relocatable program section.

## Components of MACRO Source Statements

### 3.5 Terms and Expressions

- An expression is absolute if its value is an assembly-time constant. An expression whose terms are all numbers is absolute. An expression that consists of a relocatable term minus another relocatable term from the same program section is absolute, since such an expression reduces to an assembly-time constant.
- An expression is external if it contains one or more symbols that are not defined in the current module.

Any type of expression can be used in most MACRO statements, but restrictions are placed on expressions used in the following:

- .ALIGN alignment directives
- .BLK $x$  storage allocation directives
- .IF and .IIF conditional assembly block directives
- .REPEAT repeat block directives
- .OPDEF opcode definition directives
- .ENTRY entry point directives
- .BYTE, .LONG, .WORD, .SIGNED\_BYTE, and .SIGNED\_WORD directive repetition factors
- Direct assignment statements (see Section 3.8)

See Chapter 6 for descriptions of the directives listed in the preceding list.

Expressions used in these directives and in direct assignment statements can contain only symbols that have been previously defined in the current module. They cannot contain either external symbols or symbols defined later in the current module. In addition, the expressions in these directives must be absolute. Expressions in direct assignment statements can be relocatable.

An example showing the use of expressions follows.

```
A = 2*100           ; 2*100 is an absolute expression
      .BLKB   A+50   ; A+50 is an absolute expression and
                    ; contains no undefined symbols
LAB:   .BLKW   A      ; LAB is relocatable
HALF = LAB+<A/2>    ; LAB+<A/2> is a relocatable
                    ; expression and contains no
                    ; undefined symbols
LAB2:  .BLKB   LAB2-LAB ; LAB2-LAB is an absolute expression
                    ; and contains no undefined symbols
                    ; but contains the symbol LAB3
                    ; that is defined later in this module
LAB3:  .WORD   TST+LAB+2 ; TST+LAB+2 is an external expression
                    ; because TST is an external symbol
```

## 3.6 Unary Operators

A unary operator modifies a term or an expression and indicates an action to be performed on that term or expression. Expressions modified by unary operators must be enclosed in angle brackets. You can use unary operators to indicate whether a term or expression is positive or negative. If unary plus or minus is not specified, the default value is assumed to be plus. In addition, unary operators perform radix conversion, textual conversion (including ASCII conversion), and numeric control operations, as described in the following sections. Table 3–3 summarizes the unary operators.

## Components of MACRO Source Statements

### 3.6 Unary Operators

Table 3–3 Unary Operators

| Unary Operator | Operator Name  | Example       | Operation  |
|----------------|----------------|---------------|--|
| +              | Plus sign      | +A            | Results in the positive value of A   |
| -              | Minus sign     | -A            | Results in the negative (two's complement) value of A  |
| ^B             | Binary         | ^B11000111    | Specifies that 11000111 is a binary number   |
| ^D             | Decimal        | ^D127         | Specifies that 127 is a decimal number   |
| ^O             | Octal          | ^O34          | Specifies that 34 is an octal number   |
| ^X             | Hexadecimal    | ^XFCF9        | Specifies that FCF9 is a hexadecimal number  |
| ^A             | ASCII          | ^A/ABC/       | Produces an ASCII string; the characters between the matching delimiters are converted to ASCII representation |
| ^M             | Register mask  | #^M<R3,R4,R5> | Specifies the registers R3, R4, and R5 in the register mask  |
| ^F             | Floating-point | ^F3.0         | Specifies that 3.0 is a floating-point number  |
| ^C             | Complement     | ^C24          | Produces the one's complement value of 24 (decimal)  |

More than one unary operator can be applied to a single term or to an expression enclosed in angle brackets. For example:

--+A

This construct is equivalent to:

--<+<-A>>

#### 3.6.1 Radix Control Operators

VAX MACRO accepts terms or expressions in four different radices: binary, decimal, octal, and hexadecimal. The default radix is decimal. Expressions modified by radix control operators must be enclosed in angle brackets.

##### Formats

^Bnn

^Dnn

^Onn

^Xnn

## Components of MACRO Source Statements

### 3.6 Unary Operators

#### nn

A string of characters that is legal in the specified radix. The following are the legal characters for each radix:

| Format | Radix Name  | Legal Characters  |
|--------|-------------|-------------------|
| ^Bnn   | Binary      | 0 and 1           |
| ^Dnn   | Decimal     | 0 to 9            |
| ^Onn   | Octal       | 0 to 7            |
| ^Xnn   | Hexadecimal | 0 to 9 and A to F |

Radix control operators can be included in the source program anywhere a numeric value is legal. A radix control operator affects only the term or expression immediately following it, causing that term or expression to be evaluated in the specified radix.

For example:

```
.WORD ^B00001101      ; Binary radix
.WORD ^D123           ; Decimal radix (default)
.WORD ^O47           ; Octal radix
.WORD <A+^O13>       ; 13 is in octal radix
.LONG ^X<F1C3+FFFFF-20> ; All numbers in expression
                        ; are in hexadecimal radix
```

The circumflex (^) cannot be separated from the B, D, O, or X that follows it, but the entire radix control operator can be separated by spaces and tabs from the term or expression that is to be evaluated in that radix.

The default decimal operator is needed only within an expression that has another radix control operator. In the following example, “16” is interpreted as a decimal number because it is preceded by the decimal operator ^D even though the “16” is in an expression prefixed by the octal radix control operator.

```
.LONG ^O<10000 + 100 + ^D16>
```

### 3.6.2 Textual Operators

The textual operators are the ASCII operator (^A) and the register mask operator (^M).

#### 3.6.2.1 ASCII Operator

The ASCII operator converts a string of printable characters to their 8-bit ASCII values and stores them 1 character to a byte. The string of characters must be enclosed in a pair of matching delimiters.

The delimiters can be any printable character except the space, tab, or semicolon. Use nonalphanumeric characters to avoid confusion.

#### Format

^Astring

#### string

A delimited ASCII string from 1 to 16 characters long.

The delimited ASCII string must not be larger than the data type of the operand. For example, if the ^A operator occurs in an operand in a Move Word (MOVW) instruction (the data type is a word), the delimited string cannot be more than 2 characters.

## Components of MACRO Source Statements

### 3.6 Unary Operators

For example:

```
.QUAD   ^A%1234/678%   ; Generates 8 bytes of ASCII data
MOVL    #^A/ABCD/,R0   ; Moves characters ABCD
                          ; into R0 right justified with
                          ; "A" in low-order byte and "D"
                          ; in high-order byte
CMPW    #^A/XY/,R0    ; Compares X and Y as ASCII
                          ; characters with contents of low
                          ; order 2 bytes of R0
MOVL    #^A/AB/,R0    ; Moves ASCII characters AB into
                          ; R0; "A" in low-order byte; "B" in
                          ; next; and zero the 2 high-order bytes
```

#### 3.6.2.2 Register Mask Operator

The register mask operator converts a register name or a list of register names enclosed in angle brackets into a 1- or 2-byte register mask. The register mask is used by the Push Registers (PUSHR) and Pop Registers (POPR) instructions and the .ENTRY and .MASK directives (see Chapter 6).

##### Formats

^Mreg-name

^M<reg-name-list>

##### reg-name

One of the register names or the DV or IV arithmetic trap-enable specifiers.

##### reg-name-list

A list of register names and the DV and IV arithmetic trap-enable specifiers, separated by commas.

The register mask operator sets a bit in the register mask for every register name or arithmetic trap enable specified in the list. The bits corresponding to each register name and arithmetic trap-enable specifier follow.

| Register Name | Arithmetic Trap Enable | Bits    |
|---------------|------------------------|---------|
| R0 to R11     |                        | 0 to 11 |
| R12 or AP     |                        | 12      |
| FP            |                        | 13      |
| SP            | IV                     | 14      |
|               | DV                     | 15      |

When the POPR or PUSHR instruction uses the register mask operator, R0 to R11, R12 or AP, FP, and SP can be specified. You cannot specify the PC register name and the IV and DV arithmetic trap-enable specifiers.

When the .ENTRY or .MASK directive uses the register mask operator, you can specify R2 to R11 and the IV and DV arithmetic trap-enable specifiers. However, you cannot specify R0, R1, FP, SP, and PC. IV sets the integer overflow trap, and DV sets the decimal string overflow trap.

The arithmetic trap-enable specifiers are described in Chapter 8.

## Components of MACRO Source Statements

### 3.6 Unary Operators

For example:

```
.ENTRY RT1, ^M<R3,R4,R5,R6,IV> ; Save registers R3, R4,  
                                ; R5, and R6 and set the  
                                ; integer overflow trap  
  
PUSHR #^M<R0,R1,R2,R3>        ; Save registers R0, R1,  
                                ; R2, and R3  
  
POPR #^M<R0,R1,R2,R3>        ; Restore registers R0, R1,  
                                ; R2, and R3
```

### 3.6.3 Numeric Control Operators

The numeric control operators are the floating-point operator (^F) and the complement operator (^C). The use of the numeric control operators is explained in Section 3.6.3.1 and Section 3.6.3.2.

#### 3.6.3.1 Floating-Point Operator

The floating-point operator accepts a floating-point number and converts it to its internal representation (a 4-byte value). This value can be used in any expression. VAX MACRO does not perform floating-point expression evaluation.

##### Format

^Fliteral

##### literal

A floating-point number (see Section 3.2.2).

The floating-point operator is useful because it allows a floating-point number in an instruction that accepts integers.

For example:

```
MOVL #^F3.7,R0 ; NOTE: the recommended instruction  
                                ; to move this floating-point  
MOVF #3.7,R0 ; number is the MOVF instruction
```

#### 3.6.3.2 Complement Operator

The complement operator produces the one's complement of the specified value.

##### Format

^Cterm

##### term

Any term or expression. If an expression is specified, it must be enclosed in angle brackets.

VAX MACRO evaluates the term or expression as a 4-byte value before complementing it.

For example:

```
.LONG ^C^XFF ; Produces FFFFFFF0 (hex)  
.LONG ^C25 ; Produces complement of  
            ; 25 (dec) which is  
            ; FFFFFFFE6 (hex)
```

## Components of MACRO Source Statements

### 3.7 Binary Operators

### 3.7 Binary Operators

In contrast to unary operators, binary operators specify actions to be performed on two terms or expressions. Expressions must be enclosed in angle brackets. Table 3–4 summarizes the binary operators.

Table 3–4 Binary Operators

| Binary Operator | Operator Name     | Example | Operation            |
|-----------------|-------------------|---------|----------------------|
| +               | Plus sign         | A+B     | Addition             |
| -               | Minus sign        | A-B     | Subtraction          |
| *               | Asterisk          | A*B     | Multiplication       |
| /               | Slash             | A/B     | Division             |
| @               | At sign           | A@B     | Arithmetic shift     |
| &               | Ampersand         | A&B     | Logical AND          |
| !               | Exclamation point | A!B     | Logical inclusive OR |
| \               | Backslash         | A\B     | Logical exclusive OR |

All binary operators have equal priority. Terms or expressions can be grouped for evaluation by enclosing them in angle brackets. The enclosed terms and expressions are evaluated first, and remaining operations are performed from left to right. For example:

```
.LONG      1+2*3      ; Equals 9  
.LONG      1+<2*3>   ; Equals 7
```

Note that a 4-byte result is returned from all binary operations. If you use a 1-byte or 2-byte operand, the result is the low-order bytes of the 4-byte result. VAX MACRO displays an error message if the truncation causes a loss of significance.

The following sections describe the arithmetic shift, logical AND, logical inclusive OR, and logical exclusive OR operators.

#### 3.7.1 Arithmetic Shift Operator

You use the arithmetic shift operator (@) to perform left and right arithmetic shifts of arithmetic quantities. The first argument is shifted left or right by the number of bit positions that you specify in the second argument. If the second argument is positive, the first argument is shifted left; if the second argument is negative, the first argument is shifted right. When the first argument is shifted left, the low-order bits are set to zero. When the first argument is shifted right, the high-order bits are set to the value of the original high-order bit (the sign bit).

For example:

```
.LONG      ^B101@4      ; Yields 1010000 (binary)  
.LONG      1@2          ; Yields 100 (binary)  
A = 4  
.LONG      1@A          ; Yields 10000 (binary)  
.LONG      ^X1234@-A    ; Yields 123(hex)  
MOVL      #<^B1100000@-5>,R0 ; Yields 11 (binary)
```

### 3.7.2 Logical AND Operator

The logical AND operator (&) takes the logical AND of two operands.

For example:

```
A = ^B1010
B = ^B1100
      .LONG  A&B           ; Yields 1000 (binary)
```

### 3.7.3 Logical Inclusive OR Operator

The logical inclusive OR operator (!) takes the logical inclusive OR of two operands.

For example:

```
A = ^B1010
B = ^B1100
      .LONG  A!B          ; Yields 1110 (binary)
```

### 3.7.4 Logical Exclusive OR Operator

The logical exclusive OR operator (\) takes the logical exclusive OR of two arguments.

For example:

```
A = ^B1010
B = ^B1100
      .LONG  A\B          ; Yields 0110 (binary)
```

## 3.8 Direct Assignment Statements

A direct assignment statement equates a symbol to a specific value. Unlike a symbol that you use as a label, you can redefine a symbol defined with a direct assignment statement as many times as you want.

#### Formats

```
symbol=expression
symbol==expression
```

#### symbol

A user-defined symbol.

#### expression

An expression that does not contain any undefined symbols (see Section 3.5).

The format with a single equal sign (=) defines a local symbol and the format with a double equal sign (==) defines a global symbol. See Section 3.3.3 for more information about local and global symbols.

The following three syntactic rules apply to direct assignment statements:

- An equal sign (=) or double equal sign (==) must separate the symbol from the expression which defines its value. Spaces preceding or following the direct assignment operators have no significance in the resulting value.
- Only one symbol can be defined in a single direct assignment statement.
- A direct assignment statement can be followed only by a comment field.

By Compaq convention, the symbol in a direct assignment statement is placed in the label field.

## Components of MACRO Source Statements

### 3.8 Direct Assignment Statements

For example:

```
A == 1           ; The symbol 'A' is globally
                  ;   equated to the value 1

B = A@5          ; The symbol 'B' is equated
                  ;   to 1@5 or 20(hex)

C = 127*10       ; The symbol 'C' is equated
                  ;   to 1270(dec)

D = ^X100/^X10   ; The symbol 'D' is equated
                  ;   to 10(hex)
```

### 3.9 Current Location Counter

The symbol for the current location counter, the period (`.`), always has the value of the address of the current byte. VAX MACRO sets the current location counter to zero at the beginning of the assembly and at the beginning of each new program section.

Every VAX MACRO source statement that allocates memory in the object module increments the value of the current location counter by the number of bytes allocated. For example, the directive `.LONG 0` increments the current location counter by 4. However, with the exception of the special form described below, a direct assignment statement does not increase the current location counter because no memory is allocated.

The current location counter can be explicitly set by a special form of the direct assignment statement. The location counter can be either incremented or decremented. This method of setting the location counter is often useful when defining data structures. Data storage areas should not be reserved by explicitly setting the location counter; use the `.BLKx` directives (see Chapter 6).

#### Format

`.=expression`

#### expression

An expression that does not contain any undefined symbols (see Section 3.5).

In a relocatable program section, the expression must be relocatable; that is, the expression must be relative to an address in the current program section. It may be relative to the current location counter.

For example:

```
. = .+40          ; Moves location counter forward
```

When a program section that you defined in the current module is continued, the current location counter is set to the last value of the current location counter in that program section.

When you use the current location counter in the operand field of an instruction, the current location counter has the value of the address of that operand; it does not have the value of the address of the beginning of the instruction. For this reason, you would not normally use the current location counter as a part of the operand specifier.

---

## Macro Arguments and String Operators

By using macros, you can use a single line to insert a sequence of source lines into a program.

A macro definition contains the source lines of the macro. The macro definition can optionally have formal arguments. These formal arguments can be used throughout the sequence of source lines. Later, the formal arguments are replaced by the actual arguments in the macro call.

The macro call consists of the macro name optionally followed by actual arguments. The assembler replaces the line containing the macro call with the source lines in the macro definition. It replaces any occurrences of formal arguments in the macro definition with the actual arguments specified in the macro call. This process is called the macro expansion.

The macro directives (described in Chapter 6) provide facilities for performing eight categories of functions. Table 6–2 lists these categories and the directives that fall under them.

By default, macro expansions are not printed in the assembly listing. They are printed only when the `.SHOW` directive (see description in Chapter 6) or the `/SHOW` qualifier (described in the *OpenVMS DCL Dictionary*) specifies the `EXPANSIONS` argument. In the examples in this chapter, the macro expansions are listed as they would appear if `.SHOW EXPANSIONS` was specified in the source file or `/SHOW=EXPANSIONS` was specified in the `MACRO` command string.

The remainder of this chapter describes macro arguments, created local labels, and the macro string operators.

### 4.1 Arguments in Macros

Macros have two types of arguments: actual and formal. Actual arguments are the strings given in the macro call after the name of the macro. Formal arguments are specified by name in the macro definition; that is, after the macro name in the `.MACRO` directive. Actual arguments in macro calls and formal arguments in macro definitions can be separated by commas (`,`), tabs, or spaces.

The number of actual arguments in the macro call can be less than or equal to the number of formal arguments in the macro definition. If the number of actual arguments is greater than the number of formal arguments, the assembler displays an error message.

Formal and actual arguments normally maintain a strict positional relationship. That is, the first actual argument in a macro call replaces all occurrences of the first formal argument in the macro definition. This strict positional relationship can be overridden by the use of keyword arguments (see Section 4.3).

## Macro Arguments and String Operators

### 4.1 Arguments in Macros

An example of a macro definition using formal arguments follows:

```
.MACRO STORE ARG1,ARG2,ARG3
.LONG ARG1 ; ARG1 is first argument
.WORD ARG3 ; ARG3 is third argument
.BYTE ARG2 ; ARG2 is second argument
.ENDM STORE
```

The following two examples show possible calls and expansions of the macro defined previously:

```
STORE 3,2,1 ; Macro call
.LONG 3 ; 3 is first argument
.WORD 1 ; 1 is third argument
.BYTE 2 ; 2 is second argument

STORE X,X-Y,Z ; Macro call
#.LONG X ; X is first argument
#.WORD Z ; Z is third argument
#.BYTE X-Y ; X-Y is second argument
```

### 4.2 Default Values

Default values are values that are defined in the macro definition. They are used when no value for a formal argument is specified in the macro call.

Default values are specified in the .MACRO directive as follows:

formal-argument-name = default-value

An example of a macro definition specifying default values follows:

```
.MACRO STORE ARG1=12,ARG2=0,ARG3=1000
.LONG ARG1
.WORD ARG3
.BYTE ARG2
.ENDM STORE
```

The following three examples show possible calls and expansions of the macro defined previously:

```
STORE ; No arguments supplied
.LONG 12
.WORD 1000
.BYTE 0

STORE ,5,X ; Last two arguments supplied
.LONG 12
.WORD X
.BYTE 5

STORE 1 ; First argument supplied
.LONG 1
.WORD 1000
.BYTE 0
```

### 4.3 Keyword Arguments

Keyword arguments allow a macro call to specify the arguments in any order. The macro call must specify the same formal argument names that appear in the macro definition. Keyword arguments are useful when a macro definition has more formal arguments than need to be specified in the call.

## Macro Arguments and String Operators

### 4.3 Keyword Arguments

In any one macro call, the arguments should be either all positional arguments or all keyword arguments. When positional and keyword arguments are combined in a macro, only the positional arguments correspond by position to the formal arguments; the keyword arguments are not used. If a formal argument corresponds to both a positional argument and a keyword argument, the argument that appears last in the macro call overrides any other argument definition for the same argument.

For example, the following macro definition specifies three arguments:

```
.MACRO STORE ARG1,ARG2,ARG3
.LONG ARG1
.WORD ARG3
.BYTE ARG2
.ENDM STORE
```

The following macro call specifies keyword arguments:

```
STORE ARG3=27+5/4,ARG2=5,ARG1=SYMBL
.LONG SYMBL
.WORD 27+5/4
.BYTE 5
```

Because the keywords are specified in the macro call, the arguments in the macro call need not be given in the order they were listed in the macro definition.

## 4.4 String Arguments

If an actual argument is a string containing characters that the assembler interprets as separators (such as a tab, space, or comma), the string must be enclosed by delimiters. String delimiters are usually paired angle brackets (<>).

The assembler also interprets any character after an initial circumflex (^) as a delimiter. To pass an angle bracket as part of a string, you can use the circumflex form of the delimiter.

The following are examples of delimited macro arguments:

```
<HAVE THE SUPPLIES RUN OUT?>
<LAST NAME, FIRST NAME>
<LAB: CLRL R4>
^%ARGUMENT IS <LAST,FIRST> FOR CALL%
^?EXPRESSION IS <5+3>*<4+2>?
```

In the last two examples, the initial circumflex indicates that the percent sign (%) and question mark (?) are the delimiters. Note that only the left-hand delimiter is preceded by a circumflex.

The assembler interprets a string argument enclosed by delimiters as one actual argument and associates it with one formal argument. If a string argument that contains separator characters is not enclosed by delimiters, the assembler interprets it as successive actual arguments and associates it with successive formal arguments.

For example, the following macro call has one formal argument:

```
.MACRO REPEAT STRNG
.ASCII /STRNG/
.ASCII /STRNG/
.ENDM REPEAT
```

## Macro Arguments and String Operators

### 4.4 String Arguments

The following two macro calls demonstrate actual arguments with and without delimiters:

```
REPEAT <A B C D E>
.ASCII /A B C D E/
.ASCII /A B C D E/

REPEAT A B C D E
%MACRO-E-TOOMNYARGS, Too many arguments in macro call
```

Note that the assembler interpreted the second macro call as having five actual arguments instead of one actual argument with spaces.

When a macro is called, the assembler removes any delimiters around a string before associating it with the formal arguments.

If a string contains a semicolon (;), the string must be enclosed by delimiters, or the semicolon will mark the start of the comment field.

Strings enclosed by delimiters cannot be continued on a new line.

To pass a number containing a radix or unary operator (for example, ^XF19), the entire argument must be enclosed by delimiters, or the assembler will interpret the radix operator as a delimiter.

The following are macro arguments that are enclosed in delimiters because they contain radix operators:

```
<^XF19>
<^B01100011>
<^F1.5>
```

Macros can be nested; that is, a macro definition can contain a call to another macro. If, within a macro definition, another macro is called and is passed a string argument, you must delimit the argument so that the entire string is passed to the second macro as one argument.

The following macro definition contains a call to the REPEAT macro defined in an earlier example:

```
.MACRO CNTRPT LAB1,LAB2,STR_ARG
LAB1: .BYTE LAB2-LAB1-1 ; Length of 2*string
      REPEAT <STR_ARG> ; Call REPEAT macro
LAB2:
      .ENDM CNTRPT
```

Note that the argument in the call to REPEAT is enclosed in angle brackets even though it does not contain any separator characters. The argument is thus delimited because it is a formal argument in the definition of the macro CNTRPT and will be replaced with an actual argument that may contain separator characters.

The following example calls the macro CNTRPT, which in turn calls the macro REPEAT:

```
      CNTRPT ST,FIN,<LEARN YOUR ABC'S>
ST:   .BYTE FIN-ST-1 ; Length of 2*string
      REPEAT <LEARN YOUR ABC'S> ; Call REPEAT macro
      .ASCII /LEARN YOUR ABC'S/
      .ASCII /LEARN YOUR ABC'S/
FIN:
```

## Macro Arguments and String Operators

### 4.4 String Arguments

An alternative method to pass string arguments in nested macros is to enclose the macro argument in nested delimiters. Do not use delimiters around the macro calls in the macro definitions. Each time you use the delimited argument in a macro call, the assembler removes the outermost pair of delimiters before associating it with the formal argument. This method is not recommended because it requires that you know how deeply a macro is nested.

The following macro definition also contains a call to the REPEAT macro:

```
.MACRO CNTRPT2 LAB1,LAB2,STR_ARG
LAB1: .BYTE LAB2-LAB1-1 ; Length of 2*string
      REPEAT STR_ARG ; Call REPEAT macro
LAB2:
      .ENDM CNTRPT2
```

Note that the argument in the call to REPEAT is not enclosed in angle brackets.

The following example calls the macro CNTRPT2:

```
CNTRPT2 BEG,TERM,<<MIND YOUR P'S AND Q'S>>
BEG: .BYTE TERM-BEG-1 ; Length of 2*string
      REPEAT <MIND YOUR P'S AND Q'S> ; Call REPEAT macro
      .ASCII /MIND YOUR P'S AND Q'S/
      .ASCII /MIND YOUR P'S AND Q'S/
TERM:
```

Note that even though the call to REPEAT in the macro definition is not enclosed in delimiters, the call in the expansion is enclosed because the call to CNTRPT2 contains nested delimiters around the string argument.

## 4.5 Argument Concatenation

The argument concatenation operator, the apostrophe ('), concatenates a macro argument with some constant text. Apostrophes can either precede or follow a formal argument name in the macro source.

If an apostrophe precedes the argument name, the text before the apostrophe is concatenated with the actual argument when the macro is expanded. For example, if ARG1 is a formal argument associated with the actual argument TEST, ABCDE'ARG1 is expanded to ABCDETEST.

If an apostrophe follows the formal argument name, the actual argument is concatenated with the text that follows the apostrophe when the macro is expanded. For example, if ARG2 is a formal argument associated with the actual argument MOV, ARG2'L is expanded to MOVL.

Note that the apostrophe itself does not appear in the macro expansion.

To concatenate two arguments, separate the two formal arguments with two successive apostrophes. Two apostrophes are needed because each concatenation operation discards an apostrophe from the expansion.

An example of a macro definition that uses concatenation follows:

```
.MACRO CONCAT INST,SIZE,NUM
TEST'NUM':
INST' 'SIZE R0,R'NUM
TEST'NUM'X:
      .ENDM CONCAT
```

Note that two successive apostrophes are used when concatenating the two formal arguments INST and SIZE.

## Macro Arguments and String Operators

### 4.5 Argument Concatenation

An example of a macro call and expansion follows:

```
                CONCAT  MOV,L,5
TEST5:
                MOVL   R0,R5
TEST5X:
```

### 4.6 Passing Numeric Values of Symbols

When a symbol is specified as an actual argument, the name of the symbol, not the numeric value of the symbol, is passed to the macro. The value of the symbol can be passed by inserting a backslash (\) before the symbol in the macro call. The assembler passes the characters representing the decimal value of the symbol to the macro. For example, if the symbol COUNT has a value of 2 and the actual argument specified is \COUNT, the assembler passes the string “2” to the macro; it does not pass the name of the symbol, “COUNT”.

Passing numeric values of symbols is especially useful with the apostrophe (') concatenation operator for creating new symbols.

An example of a macro definition for passing numeric values of symbols follows:

```
.MACRO  TESTDEF,TESTNO,ENTRYMASK=?^M<>?
.ENTRY  TEST'TESTNO,ENTRYMASK      ; Uses arg concatenation
.ENDM   TESTDEF
```

The following example shows a possible call and expansion of the macro defined previously:

```
COUNT = 2
        TESTDEF \COUNT
        .ENTRY  TEST2,^M<>          ; Uses arg concatenation
COUNT = COUNT + 1
        TESTDEF \COUNT,^?^M<R3,R4>?
        .ENTRY  TEST3,^M<R3,R4>    ; Uses arg concatenation
```

### 4.7 Created Local Labels

Local labels are often very useful in macros. Although you can create a macro definition that specifies local labels within it, these local labels might be duplicated elsewhere in the local label block possibly causing errors. However, the assembler can create local labels in the macro expansion that will not conflict with other local labels. These labels are called created local labels.

Created local labels range from 30000\$ to 65535\$. Each time the assembler creates a new local label, it increments the numeric part of the label name by 1. Consequently, no user-defined local labels should be in the range of 30000\$ to 65535\$.

A created local label is specified by a question mark (?) in front of the formal argument name. When the macro is expanded, the assembler creates a new local label if the corresponding actual argument is blank. If the corresponding actual argument is specified, the assembler substitutes the actual argument for the formal argument. Created local symbols can be used only in the first 31 formal arguments specified in the .MACRO directive.

Created local labels can be associated only with positional actual arguments; created local labels cannot be associated with keyword actual arguments.

## Macro Arguments and String Operators

### 4.7 Created Local Labels

The following example is a macro definition specifying a created local label:

```
        .MACRO  POSITIVE          ARG1,?L1
        TSTL   ARG1
        BGEQ   L1
        MNEGL  ARG1,ARG1
L1:     .ENDM   POSITIVE
```

The following three calls and expansions of the macro defined previously show both created local labels and a user-defined local label:

```
        POSITIVE  R0
        TSTL     R0
        BGEQ     30000$
        MNEGL    R0,R0
30000$:
        POSITIVE  COUNT
        TSTL     COUNT
        BGEQ     30001$
        MNEGL    COUNT,COUNT
30001$:
        POSITIVE  VALUE,10$
        TSTL     VALUE
        BGEQ     10$
        MNEGL    VALUE,VALUE
10$:
```

## 4.8 Macro String Operators

Following are the three macro string operators:

- %LENGTH
- %LOCATE
- %EXTRACT

These operators perform string manipulations on macro arguments and ASCII strings. They can be used only in macros and repeat blocks. The following sections describe these operators and give their formats and examples of their use.

### 4.8.1 %LENGTH Operator

#### Format

%LENGTH(string)

#### string

A macro argument or a delimited string. The string can be delimited by angle brackets or a character preceded by a circumflex (see Section 4.4).

#### Description

The %LENGTH operator returns the length of a string. For example, the value of %LENGTH(<ABCDE>) is 5.

## Macro Arguments and String Operators

### 4.8 Macro String Operators

#### Examples

The macro definition is as follows:

```
1.      .MACRO  CHK_SIZE      ARG1                ; Macro checks if ARG1
      .IF GREATER_EQUAL    %LENGTH(ARG1)-3      ; is between 3 and
      .IF LESS_THAN       6-%LENGTH(ARG1)      ; 6 characters long
      .ERROR ; Argument ARG1 is greater than 6 characters
      .ENDC ; If more than 6
      .IF_FALSE ; If less than 3
      .ERROR ; Argument ARG1 is less than 3 characters
      .ENDC ; Otherwise do nothing
      .ENDM  CHK_SIZE
```

The macro calls and expansions of the macro defined previously are as follows:

```
2.      CHK_SIZE      A                ; Macro checks if A
      .IF GREATER_EQUAL  1-3          ; is between 3 and
      .IF LESS_THAN     6-1          ; 6 characters long.
      ; Should be too short.
      .ERROR ; Argument A is greater than 6 characters
      .ENDC ; If more than 6
      .IF_FALSE ; If less than 3
      %MACRO-E-GENERR, Generated ERROR: Argument A is less than 3 characters
      .ENDC ; Otherwise do nothing

3.      CHK_SIZE      ABC                ; Macro checks if ABC
      .IF GREATER_EQUAL  3-3          ; is between 3 and
      .IF LESS_THAN     6-3          ; 6 characters long.
      ; Should be ok.
      .ERROR ; Argument ABC is greater than 6 characters
      .ENDC ; If more than 6
      .IF_FALSE ; If less than 3
      .ERROR ; Argument ABC is less than 3 characters
      .ENDC ; Otherwise do nothing
```

#### 4.8.2 %LOCATE Operator

##### Format

%LOCATE(string1,string2 [,symbol])

##### Parameters

###### string1

A substring. The substring can be written either as a macro argument or as a delimited string. The delimiters can be either angle brackets or a character preceded by a circumflex.

###### string2

The string to be searched for the substring. The string can be written either as a macro argument or as a delimited string. The delimiters can be either angle brackets or a character preceded by a circumflex.

**symbol**

An optional symbol or decimal number that specifies the position in string2 at which the assembler should start the search. If this argument is omitted, the assembler starts the search at position zero (the beginning of the string). The symbol must be an absolute symbol that has been previously defined; the number must be an unsigned decimal number. Expressions and radix operators are not allowed.

**Description**

The %LOCATE operator locates a substring within a string. If %LOCATE finds a match of the substring, it returns the character position of the first character of the match in the string. For example, the value of %LOCATE(<D>,<ABCDEF>) is 3. Note that the first character position of a string is zero. If %LOCATE does not find a match, it returns a value equal to the length of the string. For example, the value of %LOCATE(<Z>,<ABCDEF>) is 6.

The %LOCATE operator returns a numeric value that can be used in any expression.

## Macro Arguments and String Operators

### 4.8 Macro String Operators

## Examples

The macro definition is as follows:

```
1.      .MACRO BIT_NAME ARG1 ; Checks if ARG1 is in list
        .IF EQUAL %LOCATE(ARG1,<DELDLFDLTDLDMOESC>)-15
                ; If it is not, print error
        .ERROR ; ARG1 is an invalid bit name
        .ENDC ; If it is, do nothing
        .ENDM BIT_NAME
```

The macro calls and expansions of the macro defined previously are as follows:

```
2.      BIT_NAME ESC ; Is ESC in list
        .IF EQUAL 12-15 ; If it is not, print error
        .ERROR ; ESC is an invalid bit name
        .ENDC ; If it is, do nothing

        BIT_NAME FOO ; Not in list
        .IF EQUAL 15-15
                ; If it is not, print error
%MACRO-E-GENERR, Generated ERROR: FOO is an invalid bit name
        .ENDC ; If it is, do nothing
```

---

#### Note

---

If the optional symbol is specified, the search begins at the character position of string2 specified by the symbol. For example, the value of %LOCATE(<ACE>,<SPACE HOLDER>,5) is 12 because there is no match after the fifth character position.

---

### 4.8.3 %EXTRACT Operator

#### Format

%EXTRACT(symbol1,symbol2,string)

#### Parameters

##### symbol1

A symbol or decimal number that specifies the starting position of the substring to be extracted. The symbol must be an absolute symbol that has been previously defined; the number must be an unsigned decimal number. Expressions and radix operators are not allowed.

##### symbol2

A symbol or decimal number that specifies the length of the substring to be extracted. The symbol must be an absolute symbol that has been previously defined; the number must be an unsigned decimal number. Expressions and radix operators are not allowed.

##### string

A macro argument or a delimited string. The string can be delimited by angle brackets or a character preceded by a circumflex.

## Description

The %EXTRACT operator extracts a substring from a string. It returns the substring that begins at the specified position and is of the specified length. For example, the value of %EXTRACT(2,3,<ABCDEF>) is CDE. Note that the first character in a string is in position zero.

## Examples

The macro definition is as follows:

```
1.      .MACRO  RESERVE ARG1
XX = %LOCATE(<=>,ARG1)
      .IF EQUAL  XX-%LENGTH(ARG1)
      .WARN    ; Incorrect format for macro call - ARG1
      .MEXIT
      .ENDC

%EXTRACT(0,XX,ARG1)::
XX = XX+1
      .BLKB  %EXTRACT(XX,3,ARG1)
      .ENDM  RESERVE
```

The macro calls and expansions of the macro defined previously are as follows:

```
2.      RESERVE FOOBAR
XX = 6
      .IF EQUAL  XX-6
%MACRO-W-GENWRN, Generated WARNING:  Incorrect format for macro call - FOOBAR
      .MEXIT

3.      RESERVE LOCATION=12
XX = 8
      .IF EQUAL  XX-11
      .WARN    ; Incorrect format for macro call - LOCATION=12
      .MEXIT
      .ENDC

LOCATION::
XX = XX+1
      .BLKB  12
```

---

### Note

If the starting position specified is equal to or greater than the length of the string, or if the length specified is zero, %EXTRACT returns a null string (a string of zero characters).

---



---

## VAX MACRO Addressing Modes

This section summarizes the VAX addressing modes and contains examples of VAX MACRO statements that use these addressing modes. Table 5-1 summarizes the addressing modes. (Chapter 8 describes the addressing mode formats in detail.)

The following are the four types of addressing modes:

- General register
- Program counter (PC)
- Index
- Branch

Although index mode is a general register mode, it is considered separate because it can be used only in combination with another type of mode.

### 5.1 General Register Modes

The general register modes use registers R0 to R12, AP (the same as R12), FP, and SP.

The following are the eight general register modes:

- Register
- Register deferred
- Autoincrement
- Autoincrement deferred
- Autodecrement
- Displacement
- Displacement deferred
- Literal

# VAX MACRO Addressing Modes

## 5.1 General Register Modes

Table 5–1 Addressing Modes

| Type                    | Addressing Mode        | Format                  | Hex Value   | Description   | Can Be Indexed?   |     |
|-------------------------|------------------------|-------------------------|---|---|---|-----|
| General register        | Register               | Rn                      | 5   | Register contains the operand.  | No  |     |
|                         | Register deferred      | (Rn)                    | 6   | Register contains the address of the operand.   | Yes   |     |
|                         | Autoincrement          | (Rn)+                   | 8   | Register contains the address of the operand; the processor increments the register contents by the size of the operand data type.  | Yes   |     |
|                         | Autoincrement deferred | @(Rn)+                  | 9   | Register contains the address of the operand address; the processor increments the register contents by 4.  | Yes   |     |
|                         | Autodecrement          | -(Rn)                   | 7   | The processor decrements the register contents by the size of the operand data type; the register then contains the address of the operand.   | Yes   |     |
|                         | Displacement           |                         | dis(Rn)   | A   | The sum of the contents of the register and the displacement is the address of the operand; B <sup>^</sup> , W <sup>^</sup> , and L <sup>^</sup> respectively indicate byte, word, and longword displacement. | Yes |
|                         |                        |                         | B <sup>^</sup> dis(Rn)  | C   |   |     |
|                         |                        |                         | W <sup>^</sup> dis(Rn)  | E   |   |     |
| Displacement deferred   |                        | @dis(Rn)                | B   | The sum of the contents of the register and the displacement is the address of the operand address; B <sup>^</sup> , W <sup>^</sup> , and L <sup>^</sup> respectively indicate, byte, word, and longword displacement.      | Yes   |     |
|                         |                        | @B <sup>^</sup> dis(Rn) | D   |   |   |     |
|                         |                        | @W <sup>^</sup> dis(Rn) | F   |   |   |     |
| Literal                 |                        | #literal                | 0-3   | The literal specified is the operand; the literal is stored as a short literal.   | No  |     |
|                         |                        | S <sup>^</sup> #literal |   |   |   |     |
| Program counter         | Relative               | address                 |   | The address specified is the address of the operand; the address is stored as a displacement from the PC; B <sup>^</sup> , W <sup>^</sup> , and L <sup>^</sup> respectively indicate byte, word, and longword displacement. | Yes   |     |
|                         |                        | B <sup>^</sup> address  | A   |   |   |     |
|                         |                        | W <sup>^</sup> address  | C   |   |   |     |
|                         | L <sup>^</sup> address | E                       |   |   |   |     |
| Relative deferred       | @address               | B                       | The address specified is the address of the operand address; the address specified is stored as a displacement from the PC; B <sup>^</sup> , W <sup>^</sup> , and L <sup>^</sup> indicate byte, word, and longword displacement respectively. | Yes   |   |     |
| @B <sup>^</sup> address | D                      |                         |   |   |   |     |
| @W <sup>^</sup> address | F                      |                         |   |   |   |     |

**Key:**

- Rn**—Any general register R0 to R12. Note that the AP, FP, or SP register can be used in place of Rn.
- Rx**—Any general register R0 to R12. Note that the AP, FP, or SP register can be used in place of Rx. Rx cannot be the same as the Rn specified in the base-mode for certain base modes (see Section 5.3).
- dis**—An expression specifying a displacement.
- address**—An expression specifying an address.
- literal**—An expression, an integer constant, or a floating-point constant.

(continued on next page)

## VAX MACRO Addressing Modes

### 5.1 General Register Modes

**Table 5–1 (Cont.) Addressing Modes**

| Type   | Addressing Mode | Format                 | Hex Value | Description   | Can Be Indexed? |
|--------|-----------------|------------------------|-----------|---|-----------------|
|        | Absolute        | @#address              | 9         | The address specified is the address of the operand; the address specified is stored as an absolute virtual address, not as a displacement.   | Yes             |
|        | Immediate       | #literal<br>I^#literal | 8         | The literal specified is the operand; the literal is stored as a byte, word, longword, or quadword.   | No              |
|        | General         | G^address              | —         | The address specified is the address of the operand; if the address is defined as relocatable, the linker stores the address as a displacement from the PC; if the address is defined as an absolute virtual address, the linker stores the address as an absolute value.   | Yes             |
| Index  | Index           | base-mode[Rx]          | 4         | The base-mode specifies the base address and the register specifies the index; the sum of the base address and the product of the contents of Rx and the size of the operand data type is the address of the operand; base mode can be any addressing mode except register, immediate, literal, index, or branch. | No              |
| Branch | Branch          | address                | —         | The address specified is the operand; this address is stored as a displacement from the PC; branch mode can only be used with the branch instructions.  | No              |

**Key:**

**Rn**—Any general register R0 to R12. Note that the AP, FP, or SP register can be used in place of Rn.  
**Rx**—Any general register R0 to R12. Note that the AP, FP, or SP register can be used in place of Rx. Rx cannot be the same as the Rn specified in the base-mode for certain base modes (see Section 5.3).  
**dis**—An expression specifying a displacement.  
**address**—An expression specifying an address.  
**literal**—An expression, an integer constant, or a floating-point constant.

#### 5.1.1 Register Mode

In register mode, the operand is the contents of the specified register, except in the following cases:

- For quadword, D\_floating, G\_floating, or variable-bit field operands, the operand is the contents of register n concatenated with the contents of register n+1.
- For octaword and H\_floating operands, the operand is the contents of register n concatenated with the contents of registers n+1, n+2, and n+3.

In each of these cases, the least significant bytes of the operand are in register n and the most significant bytes are in the highest register used, either n+1 or n+3.

The results of the operation are unpredictable if you use the PC in register mode or if you use a large data type that extends the operand into the PC.

## VAX MACRO Addressing Modes

### 5.1 General Register Modes

#### Formats

Rn

AP

FP

SP

n

A number in the range 0 to 12.

#### Example

```
CLRB  R0      ; Clear lowest byte of R0
CLRQ  R1      ; Clear R1 and R2
TSTW  R10     ; Test lower word of R10
INCL  R4      ; Add 1 to R4
```

#### 5.1.2 Register Deferred Mode

In register deferred mode, the register contains the address of the operand. Register deferred mode can be used with index mode (see Section 5.3).

#### Formats

(Rn)

(AP)

(FP)

(SP)

#### Parameters

n

A number in the range 0 to 12.

#### Example

```
MOVAL  LDATA,R3      ; Move address of LDATA to R3
CMLPL  (R3),R0       ; Compare value at LDATA to R0
BEQL   10$,          ; If they are the same, ignore
CLRL   (R3)          ; Clear longword at LDATA
10$:   MOVL  (SP),R1   ; Copy top item of stack into R1
MOVZBL (AP),R4       ; Get number of arguments in call
```

#### 5.1.3 Autoincrement Mode

In autoincrement mode, the register contains the address of the operand. After evaluating the operand address contained in the register, the processor increments that address by the size of the operand data type. The processor increments the contents of the register by 1, 2, 4, 8, or 16 for a byte, word, longword, quadword, or octaword operand, respectively.

Autoincrement mode can be used with index mode (see Section 5.3), but the index register cannot be the same as the register specified in autoincrement mode.

#### Formats

(Rn)+

(AP)+

(FP)+

(SP)+

## VAX MACRO Addressing Modes

### 5.1 General Register Modes

#### Parameters

**n**

A number in the range 0 to 12.

#### Example

```
MOVAL  TABLE,R1          ; Get address of TABLE.
CLRQ   (R1)+              ; Clear first and second longwords
CLRRL  (R1)+              ;   and third longword in TABLE;
                               ;   leave R1 pointing to TABLE+12.

MOVAB  BYTARR,R2          ; Get address of BYTARR.
INCB   (R2)+              ; Increment first byte of BYTARR
INCB   (R2)+              ;   and second.

XORL3  (R3)+,(R4)+,(R5)+ ; Exclusive-OR the 2 longwords
                               ;   whose addresses are stored in
                               ;   R3 and R4 and store result in
                               ;   address contained in R5; then
                               ;   add 4 to R3, R4, and R5.
```

#### 5.1.4 Autoincrement Deferred Mode

In autoincrement deferred mode, the register contains an address that is the address of the operand address (a pointer to the operand). After evaluating the operand address, the processor increments the contents of the register by 4 (the size in bytes of an address).

Autoincrement deferred mode can be used with index mode (see Section 5.3), but the index register cannot be the same as the register specified in autoincrement deferred mode.

#### Formats

@(Rn)+

@(AP)+

@(FP)+

@(SP)+

#### Parameters

**n**

A number in the range 0 to 12.

#### Example

```
MOVAL  PNTLIS,R2          ; Get address of pointer list.
CLRQ   @(R2)+             ; Clear quadword pointed to by
                               ;   first absolute address in PNTLIS;
                               ;   then add 4 to R2.

CLRBL  @(R2)+             ; Clear byte pointed to by second
                               ;   absolute address in PNTLIS
                               ;   then add 4 to R2.

MOVL   R10,@(R0)+        ; Move R10 to location whose address
                               ;   is pointed to by R0; then add 4
                               ;   to R0.
```

## VAX MACRO Addressing Modes

### 5.1 General Register Modes

#### 5.1.5 Autodecrement Mode

In autodecrement mode, the processor decrements the contents of the register by the size of the operand data type; the register contains the address of the operand. The processor decrements the register by 1, 2, 4, 8, or 16 for byte, word, longword, quadword, or octaword operands, respectively.

Autodecrement mode can be used with index mode (see Section 5.3), but the index register cannot be the same as the register specified in autodecrement mode.

##### Formats

-(Rn)

-(AP)

-(FP)

-(SP)

##### Parameters

**n**

A number in the range 0 to 12.

#### Example

```
CLRO    -(R1)           ; Subtract 8 from R1 and zero
                          ; the octaword whose address
                          ; is in R1.

MOVZBL  R3,-(SP)       ; Push the zero-extended low byte
                          ; of R3 onto the stack as a
                          ; longword.

CMPB    R1,-(R0)       ; Subtract 1 from R0 and compare
                          ; low byte of R1 with byte whose
                          ; address is now in R0.
```

#### 5.1.6 Displacement Mode

In displacement mode, the contents of the register plus the displacement (sign-extended to a longword) produce the address of the operand.

Displacement mode can be used with index mode (see Section 5.3). If used in displacement mode, the index register can be the same as the base register.

##### Formats

dis(Rn)

dis(AP)

dis(FP)

dis(SP)

##### Parameters

**n**

A number in the range 0 to 12.

##### **dis**

An expression specifying a displacement; the expression can be preceded by one of the following displacement length specifiers, which indicate the number of bytes needed to store the displacement:

## VAX MACRO Addressing Modes

### 5.1 General Register Modes

| Displacement Length Specifier | Meaning                                       |
|-------------------------------|---|
| B <sup>^</sup>                | Displacement requires 1 byte.                 |
| W <sup>^</sup>                | Displacement requires one word (2 bytes).     |
| L <sup>^</sup>                | Displacement requires one longword (4 bytes). |

If no displacement length specifier precedes the expression, and the value of the expression is known, the assembler chooses the smallest number of bytes (1, 2, or 4) needed to store the displacement. If no length specifier precedes the expression, and the value of the expression is unknown, the assembler reserves one word (2 bytes) for the displacement. Note that if the displacement is either relocatable or defined later in the source program, the assembler considers it unknown. If the actual displacement does not fit in the memory reserved, the linker displays an error message.

#### Example

```

MOVAB  KEYWORDS,R3          ; Get address of KEYWORDS.
MOVB   B^IO(R3),R4          ; Get byte whose address is IO
                                ; plus address of KEYWORDS;
                                ; the displacement is stored
                                ; as a byte.
MOVB   B^ACCOUNT(R3),R5     ; Get byte whose address is
                                ; ACCOUNT plus address of
                                ; KEYWORDS; the displacement
                                ; is stored as a byte.
CLRW   L^STA(R1)            ; Clear word whose address
                                ; is STA plus contents of R1;
                                ; the displacement is stored
                                ; as a longword.
MOVL   R0,-2(R2)            ; Move R0 to address that is -2
                                ; plus the contents of R2; the
                                ; displacement is stored as a
                                ; byte.
TSTB   EXTRN(R3)            ; Test the byte whose address
                                ; is EXTRN plus the address
                                ; of KEYWORDS; the displace-
                                ; ment is stored as a word,
                                ; since EXTRN is undefined.
MOVAB  2(R5),R0             ; Move <contents of R5> + 2
                                ; to R0.

```

#### Note

If the value of the displacement is zero, and no displacement length is specified, the assembler uses register deferred mode rather than displacement mode.

## VAX MACRO Addressing Modes

### 5.1 General Register Modes

#### 5.1.7 Displacement Deferred Mode

In displacement deferred mode, the contents of the register plus the displacement (sign-extended to a longword) produce the address of the operand address (a pointer to the operand).

Displacement deferred mode can be used with index mode (see Section 5.3). If used in displacement deferred mode, the index register can be the same as the base register.

##### Formats

@dis(Rn)

@dis(AP)

@dis(FP)

@dis(SP)

##### Parameters

**n**

A number in the range 0 to 12.

**dis**

An expression specifying a displacement; the expression can be preceded by one of the following displacement length specifiers, which indicate the number of bytes needed to store the displacement:

| Displacement Length Specifier | Meaning                                       |
|-------------------------------|---|
| B <sup>^</sup>                | Displacement requires 1 byte.                 |
| W <sup>^</sup>                | Displacement requires one word (2 bytes).     |
| L <sup>^</sup>                | Displacement requires one longword (4 bytes). |

If no displacement length specifier precedes the expression, and the value of the expression is known, the assembler chooses the smallest number of bytes (1, 2, or 4) needed to store the displacement. If no length specifier precedes the expression, and the value of the expression is unknown, the assembler reserves one word (2 bytes) for the displacement. Note that if the displacement is either relocatable or defined later in the source program, the assembler considers it unknown. If the actual displacement does not fit in the memory the assembler has reserved, the linker displays an error message.

#### Example

```
MOVAL   ARRPOINT,R6           ; Get address of array of pointers.
CLRL    @16(R6)               ; Clear longword pointed to by
                                ; longword whose address is
                                ; <16 + address of ARRPOINT>; the
                                ; displacement is stored as a byte.

MOVL    @B^OFFS(R6),@RSOFF(R6) ; Move the longword pointed to
                                ; by longword whose address is
                                ; <OFFS + address of ARRPOINT>
                                ; to the address pointed to by
                                ; longword whose address is
                                ; <RSOFFS + address of ARRPOINT>;
                                ; the first displacement is
                                ; stored as a byte; the second
                                ; displacement is stored as a word.
```

## VAX MACRO Addressing Modes

### 5.1 General Register Modes

```

CLRW    @84(R2)          ; Clear word pointed to by
                        ; <longword at 84 + contents of R2>;
                        ; the assembler uses byte
                        ; displacement automatically.

```

#### 5.1.8 Literal Mode

In literal mode, the value of the literal is stored in the addressing mode byte.

##### Formats

```

#literal
S^#literal

```

##### Parameters

##### literal

An expression, an integer constant, or a floating-point constant. The literal must fit in the short literal form. That is, integers must be in the range 0 to 63 and floating-point constants must be one of the 64 values listed in Table 5-2 and Table 5-3. Floating-point short literals are stored with a 3-bit exponent and a 3-bit fraction. Table 5-2 and Table 5-3 also show the value of the exponent and the fraction for each literal. See Section 8.7.8 for information on the format of short literals.

**Table 5-2 Floating-Point Literals Expressed as Decimal Numbers**

| Exponent | 0    | 1      | 2     | 3      | 4    | 5      | 6     | 7      |
|----------|------|--------|-------|--------|------|--------|-------|--------|
| 0        | 0.5  | 0.5625 | 0.625 | 0.6875 | 0.75 | 0.8125 | 0.875 | 0.9375 |
| 1        | 1.0  | 1.125  | 1.25  | 1.37   | 1.5  | 1.625  | 1.75  | 1.875  |
| 2        | 2.0  | 2.25   | 2.5   | 2.75   | 3.0  | 3.25   | 3.5   | 3.75   |
| 3        | 4.0  | 4.5    | 5.0   | 5.5    | 6.0  | 6.5    | 7.0   | 7.5    |
| 4        | 8.0  | 9.0    | 10.0  | 11.0   | 12.0 | 13.0   | 14.0  | 15.0   |
| 5        | 16.0 | 18.0   | 20.0  | 22.0   | 24.0 | 26.0   | 28.0  | 30.0   |
| 6        | 32.0 | 36.0   | 40.0  | 44.0   | 48.0 | 52.0   | 56.0  | 60.0   |
| 7        | 64.0 | 72.0   | 80.0  | 88.0   | 96.0 | 104.0  | 112.0 | 120.0  |

**Table 5-3 Floating-Point Literals Expressed as Rational Numbers**

| Exponent | 0   | 1     | 2     | 3     | 4     | 5     | 6     | 7     |
|----------|-----|-------|-------|-------|-------|-------|-------|-------|
| 0        | 1/2 | 9/16  | 5/8   | 11/16 | 3/4   | 13/16 | 7/8   | 15/16 |
| 1        | 1   | 1-1/8 | 1-1/4 | 1-3/8 | 1-1/2 | 1-5/8 | 1-3/4 | 1-7/8 |
| 2        | 2   | 2-1/4 | 2-1/2 | 2-3/4 | 3     | 3-1/4 | 3-1/2 | 3-3/4 |
| 3        | 4   | 4-1/2 | 5     | 5-1/2 | 6     | 6-1/2 | 7     | 7-1/2 |
| 4        | 8   | 9     | 10    | 11    | 12    | 13    | 14    | 15    |
| 5        | 16  | 18    | 20    | 22    | 24    | 26    | 28    | 30    |
| 6        | 32  | 36    | 40    | 44    | 48    | 52    | 56    | 60    |
| 7        | 64  | 72    | 80    | 88    | 96    | 104   | 112   | 120   |

## VAX MACRO Addressing Modes

### 5.1 General Register Modes

#### Example

```
MOVL    #1,R0           ; R0 is set to 1; the 1 is stored
                       ; in the instruction as a short
                       ; literal.

MOVVB   S^#CR,R1       ; The low byte of R1 is set
                       ; to the value CR.
                       ; CR is stored in the instruction
                       ; as a short literal.
                       ; If CR is not in range 0-63,
                       ; the linker produces a
                       ; truncation error.

MOVFB   #0.625,R6      ; R6 is set to the floating-point
                       ; value 0.625; it is stored
                       ; in the floating-point short
                       ; literal form.
```

#### Notes

1. When you use the #literal format, the assembler chooses whether to use literal mode or immediate mode (see Section 5.2.4). The assembler uses immediate mode if any of the following conditions is satisfied:

- The value of the literal does not fit in the short literal form.
- The literal is a relocatable or external expression (see Section 3.5).
- The literal is an expression that contains undefined symbols.

The difference between immediate mode and literal mode is the amount of storage that it takes to store the literal in the instruction.

2. The S^#literal format forces the assembler to use literal mode.

### 5.2 Program Counter Modes

The program counter (PC) modes use the PC for a general register. Following are the five program counter modes:

- Relative
- Relative deferred
- Absolute
- Immediate
- General

In Section 8.8, Table 8-6 is a summary of PC addressing.

#### 5.2.1 Relative Mode

In relative mode, the address specified is the address of the operand. The assembler stores the address as a displacement from the PC.

Relative mode can be used with index mode (see Section 5.3).

#### Format

address

**Parameters**

**address**

An expression specifying an address; the expression can be preceded by one of the following displacement length specifiers, which indicate the number of bytes needed to store the displacement.

| Displacement Length Specifier | Meaning                                       |
|-------------------------------|---|
| B <sup>^</sup>                | Displacement requires 1 byte.                 |
| W <sup>^</sup>                | Displacement requires one word (2 bytes).     |
| L <sup>^</sup>                | Displacement requires one longword (4 bytes). |

If no displacement length specifier precedes the address expression, and the value of the expression is known, the assembler chooses the smallest number of bytes (1, 2, or 4) needed to store the displacement. If no length specifier precedes the address expression, and the value of the expression is unknown, the assembler uses the default displacement length (see the description of .DEFAULT in Chapter 6). If the address expression is either defined later in the program or defined in another program section, the assembler considers the value unknown.

**Example**

```
MOVL LABEL,R1 ; Get longword at LABEL; the
               ; assembler uses default
               ; displacement unless LABEL was
               ; previously defined in this
               ; section

CMPL W<DATA+4>,R10 ; Compare R10 with longword at
                  ; address DATA+4; CMPL
                  ; uses a word displacement
```

**5.2.2 Relative Deferred Mode**

In relative deferred mode, the address specified is the address of the operand address (a pointer to the operand). The assembler stores the address specified as a displacement from the PC.

Relative deferred mode can be used with index mode (see Section 5.3).

**Format**

@address

**Parameters**

**address**

An expression specifying an address; the expression can be preceded by one of the following displacement length specifiers, which indicate the number of bytes needed to store the displacement:

| Displacement Length Specifier | Meaning                                       |
|-------------------------------|---|
| B <sup>^</sup>                | Displacement requires 1 byte.                 |
| W <sup>^</sup>                | Displacement requires one word (2 bytes).     |
| L <sup>^</sup>                | Displacement requires one longword (4 bytes). |

## VAX MACRO Addressing Modes

### 5.2 Program Counter Modes

If no displacement length specifier precedes the address expression, and the value of the expression is known, the assembler chooses the smallest number of bytes (1, 2, or 4) needed to store the displacement. If no length specifier precedes the address expression, and the value of the expression is unknown, the assembler uses the default displacement length (see the description of `.DEFAULT` in Chapter 6). If the address expression is either defined later in the program or defined in another program section, the assembler considers the value unknown.

#### Example

```
CLRL    @W^PNTR        ; Clear longword pointed to by
                    ; longword at PNTR; the assembler
                    ; uses a word displacement

INCB    @L^COUNTS+4   ; Increment byte pointed to by
                    ; longword at COUNTS+4; assembler
                    ; uses a longword displacement
```

#### 5.2.3 Absolute Mode

In absolute mode, the address specified is the address of the operand. The address is stored as an absolute virtual address (compare relative mode, where the address is stored as a displacement from the PC).

Absolute mode can be used with index mode (see Section 5.3).

##### Format

@#address

##### Parameters

###### address

An expression specifying an address.

#### Example

```
CLRL    @#^X1100       ; Clear the contents of location 1100(hex)

CLRB    @#ACCOUNT      ; Clear the contents of location
                    ; ACCOUNT; the address is stored
                    ; absolutely, not as a displacement

CALLS   #3,@#SYS$FAO   ; Call the procedure SYS$FAO with
                    ; three arguments on the stack
```

#### 5.2.4 Immediate Mode

In immediate mode, the literal specified is the operand.

##### Formats

#literal

I^#literal

##### Parameters

###### literal

An expression, an integer constant, or a floating-point constant.

## VAX MACRO Addressing Modes

### 5.2 Program Counter Modes

#### Example

```
MOVL      #1000,R0      ; R0 is set to 1000; the operand 1000
                          ; is stored in a longword
MOVB      #BAR,R1      ; The low byte of R1 is set
                          ; to the value of BAR
MOVF      #0.1,R6      ; R6 is set to the floating-point
                          ; value 0.1; it is stored
                          ; as a 4-byte floating-point
                          ; value (it cannot be
                          ; represented as a short literal)
ADDL2     I^#5,R0      ; The 5 is stored in a longword
                          ; because the I^ forces the
                          ; assembler to use immediate mode
MOVG      #0.2,R6      ; The value 0.2 is converted
                          ; to its G_FLOATING representation
MOVG      #PI,R6       ; The value contained in PI is
                          ; moved to R6; no conversion is
                          ; performed
```

#### Notes

1. When you use the #literal format, the assembler chooses whether to use literal mode (Section 5.1.8) or immediate mode. If the literal is an integer from 0 to 63 or a floating-point constant that fits in the short literal form, the assembler uses literal mode. If the literal is an expression, the assembler uses literal mode if all the following conditions are met:

- The expression is absolute.
- The expression contains no undefined symbols.
- The value of the expression fits in the short literal form.

In all other cases, the assembler uses immediate mode.

The difference between immediate mode and literal mode is the amount of storage required to store the literal in the instruction. The assembler stores an immediate mode literal in a byte, word, or longword depending on the operand data type.

2. The I^#literal format forces the assembler to use immediate mode.
3. You can specify floating-point numbers two ways: as a numeric value or as a symbol name. The assembler handles these values in different ways, as follows:
  - Numeric values are converted to the appropriate internal floating-point representation.
  - Symbols are not converted. The assembler assumes that the values have already been converted to internal floating-point representation.

Once the assembler obtains the value, it tries to convert the internal representation of the value to a short floating literal. If conversion fails, the assembler uses immediate mode; if conversion succeeds, the assembler uses short floating literal mode.

## VAX MACRO Addressing Modes

### 5.2 Program Counter Modes

#### 5.2.5 General Mode

In general mode, the address you specify is the address of the operand. The linker converts the addressing mode to either relative or absolute mode. If the address is relocatable, the linker converts general mode to relative mode. If the address is absolute, the linker converts general mode to absolute mode. You should use general mode to write position-independent code when you do not know whether the address is relocatable or absolute. A general addressing mode operand requires 5 bytes of storage.

You can use general mode with index mode (see Section 5.3).

#### Format

G^address

#### Parameters

##### address

An expression specifying an address.

#### Example

```
CLRL    G^LABEL_1          ; Clears the longword at LABEL_1
                          ; If LABEL_1 is defined as
                          ; absolute then general mode is
                          ; converted to absolute
                          ; mode; if it is defined as
                          ; relocatable, then general mode is
                          ; converted to relative mode

CALLS   #5,G^SYS$SERVICE ; Calls procedure SYS$SERVICE
                          ; with 5 arguments on stack
```

### 5.3 Index Mode

Index mode is a general register mode that can be used only in combination with another mode (the base mode). The base mode can be any addressing mode except register, immediate, literal, index, or branch. The assembler first evaluates the base mode to get the base address. To get the operand address, the assembler multiplies the contents of the index register by the number of bytes of the operand data type, then adds the result to the base address.

Combining index mode with the other addressing modes produces the following addressing modes:

- Register deferred index
- Autoincrement index
- Autoincrement deferred index
- Autodecrement index
- Displacement index
- Displacement deferred index
- Relative index
- Relative deferred index
- Absolute index
- General index

The process of first evaluating the base mode and then adding the index register is the same for each of these modes.

**Formats**

base-mode[Rx]  
base-mode[AP]  
base-mode[FP]  
base-mode[SP]

**Parameters**

**base-mode**

Any addressing mode except register, immediate, literal, index, or branch, specifying the base address.

**x**

A number in the range 0 to 12, specifying the index register.

Table 5-4 lists the formats of index mode addressing.

**Example**

```

;
; Register deferred index mode
;
OFFS=20
MOVAB  BLIST,R9      ; Define OFFS
                    ; Get address of BLIST
MOVL   #OFFS,R1     ; Set up index register
CLR    (R9)[R1]     ; Clear byte whose address
                    ; is the address of BLIST
                    ; plus 20*1

CLRQ   (R9)[R1]     ; Clear quadword whose
                    ; address is the address
                    ; of BLIST plus 20*8

CLRO   (R9)[R1]     ; Clear octaword whose
                    ; address is the address
                    ; of BLIST plus 20*16
;
; Autoincrement index mode
;
CLR    (R9)+[R1]    ; Clear word whose address
                    ; is address of BLIST plus
                    ; 20*2; R9 now contains
                    ; address of BLIST+2
;
; Autoincrement deferred index mode
;
MOVAL  POINT,R8     ; Get address of POINT
MOVL   #30,R2      ; Set up index register
CLR    @(R8)+[R2]   ; Clear word whose address
                    ; is 30*2 plus the address
                    ; stored in POINT; R8 now
                    ; contains 4 plus address of
                    ; POINT
;
; Displacement deferred index mode
;
MOVAL  ADDARR,R9    ; Get address of address array
MOVL   #100,R1     ; Set up index register
TSTF   @40(R9)[R1] ; Test floating-point value
                    ; whose address is 100*4 plus
                    ; the address stored at
                    ; (ADDARR+40)

```

## VAX MACRO Addressing Modes

### 5.3 Index Mode

**Table 5–4 Index Mode Addressing**

| Mode   | Format        |
|--|---------------|
| Register Deferred Index <sup>1,2</sup>       | (Rn)[Rx]      |
| Autoincrement Index <sup>1,2</sup>           | (Rn)+[Rx]     |
| Autoincrement Deferred Index <sup>1,2</sup>  | @(Rn)+[Rx]    |
| Autodecrement Index <sup>1,2</sup>           | -(Rn)[Rx]     |
| Displacement Index <sup>1,2,3</sup>          | dis(Rn)[Rx]   |
| Displacement Deferred Index <sup>1,2,3</sup> | @dis(Rn)[Rx]  |
| Relative Index <sup>2</sup>                  | address[Rx]   |
| Relative Deferred Index <sup>2</sup>         | @address[Rx]  |
| Absolute Index <sup>2</sup>                  | @#address[Rx] |
| General Index <sup>2</sup>                   | G^address[Rx] |

<sup>1</sup>Rn—Any general register R0 to R12 or the AP, FP, or SP register.

<sup>2</sup>Rx—Any general register R0 to R12 or the AP, FP, or SP register. Rx cannot be the same register as Rn in the autoincrement index, autoincrement deferred index, and decrement index addressing modes.

<sup>3</sup>dis—An expression specifying a displacement.

#### Notes

1. If the base mode alters the contents of its register (autoincrement, autoincrement deferred, and autodecrement), the index mode cannot specify the same register.
2. The index register is added to the address after the base mode is completely evaluated. For example, in autoincrement deferred index mode, the base register contains the address of the operand address. The index register (times the length of the operand data type) is added to the operand address rather than to the address stored in the base register.

## 5.4 Branch Mode

In branch mode, the address is stored as an implied displacement from the PC. This mode can be used only in branch instructions. The displacement for conditional branch instructions and the BRB instruction is stored in a byte. The displacement for the BRW instruction is stored in a word (2 bytes). A byte displacement allows a range of 127 bytes forward and 128 bytes backward. A word displacement allows a range of 32,767 bytes forward and 32,768 bytes backward. The displacement is relative to the updated PC, the byte past the byte or word where the displacement is stored. See Chapter 9 for more information on the branch instructions.

#### Format

address

## VAX MACRO Addressing Modes 5.4 Branch Mode

### Parameters

#### address

An expression that represents an address.

### Example

```
ADDL3  (R1)+,R0,TOTAL      ; Total values and set condition
                               ; codes
BLEQ   LABEL1              ; Branch to LABEL1 if result is
                               ; less than or equal to 0
BRW    LABEL                ; Branch unconditionally to LABEL
```



---

## VAX MACRO Assembler Directives

The general assembler directives provide facilities for performing 11 types of functions. Table 6–1 lists these types of functions and their directives.

The macro directives provide facilities for performing eight categories of functions. Table 6–2 lists these categories and their associated directives. Chapter 4 describes macro arguments and string operators.

The remainder of this chapter describes both the general assembler directives and the macro directives, showing their formats and giving examples of their use. For ease of reference, the directives are presented in alphabetical order. Appendix C contains a summary of all assembler directives.

**Table 6–1 Summary of General Assembler Directives**

| Category                    | Directives <sup>1</sup>   |
|-----------------------------|---|
| Listing control directives  | .SHOW (.LIST)<br>.NOSHOW(.NLIST)<br>.TITLE<br>.SUBTITLE (.SBTTL)<br>.IDENT<br>.PAGE   |
| Message display directives  | .PRINT<br>.WARN<br>.ERROR   |
| Assembler option directives | .ENABLE (.ENABL)<br>.DISABLE(.DSABL)<br>.DEFAULT  |
| Data storage directives     | .BYTE<br>.WORD<br>.LONG<br>.ADDRESS<br>.QUAD<br>.OCTA<br>.PACKED<br>.ASCII<br>.ASCIC<br>.ASCID<br>.ASCIZ<br>.F_FLOATING (.FLOAT)<br>.D_FLOATING (.DOUBLE)<br>.G_FLOATING<br>.H_FLOATING<br>.SIGNED_BYTE<br>.SIGNED_WORD |

---

<sup>1</sup>The alternate form, if any, is given in parentheses.

(continued on next page)

## VAX MACRO Assembler Directives

**Table 6–1 (Cont.) Summary of General Assembler Directives**

| Category   | Directives <sup>1</sup>   |
|--|---|
| Location control directives                              | .ALIGN<br>.EVEN<br>.ODD<br>.BLKA<br>.BLKB<br>.BLKD<br>.BLKF<br>.BLKG<br>.BLKH<br>.BLKL<br>.BLKO<br>.BLKQ<br>.BLKW<br>.END |
| Program sectioning directives                            | .PSECT<br>.SAVE_PSECT (.SAVE)<br>.RESTORE_PSECT (.RESTORE)  |
| Symbol control directives                                | .GLOBAL (.GLOBL)<br>.EXTERNAL (.EXTRN)<br>.DEBUG<br>.WEAK   |
| Routine entry point definition directives                | .ENTRY<br>.TRANSFER<br>.MASK  |
| Conditional and subconditional assembly block directives | .IF<br>.ENDC<br>.IF_FALSE (.IFF)<br>.IF_TRUE (.IFT)<br>.IF_TRUE_FALSE (.IFTF)<br>.IIF                                     |
| Cross-reference directives                               | .CROSS<br>.NOCROSS  |
| Instruction generation directives                        | .OPDEF<br>.REF1<br>.REF2<br>.REF4<br>.REF8<br>.REF16  |
| Linker option record directive                           | .LINK   |

<sup>1</sup>The alternate form, if any, is given in parentheses.

**Table 6–2 Summary of Macro Directives**

| Category                    | Directives <sup>1</sup> |
|-----------------------------|-------------------------|
| Macro definition directives | .MACRO<br>.ENDM         |
| Macro library directives    | .LIBRARY<br>.MCALL      |

<sup>1</sup>The alternate form, if any, is given in parentheses.

(continued on next page)

**Table 6–2 (Cont.) Summary of Macro Directives**

| <b>Category</b>                    | <b>Directives<sup>1</sup></b> |
|------------------------------------|-------------------------------|
| Macro deletion directive           | .MDELETE                      |
| Macro exit directive               | .MEXIT                        |
| Argument attribute directives      | .NARG<br>.NCHR<br>.NTYPE      |
| Indefinite repeat block directives | .IRP<br>.IRPC                 |
| Repeat block directives            | .REPEAT (.REPT)               |
| End range directive                | .ENDR                         |

<sup>1</sup>The alternate form, if any, is given in parentheses.

## Assembler Directives

### .ADDRESS

---

### .ADDRESS

Address storage directive

#### Format

```
.ADDRESS address-list
```

#### Parameter

##### **address-list**

A list of symbols or expressions, separated by commas (,), which VAX MACRO interprets as addresses. Repetition factors are not allowed.

#### Description

.ADDRESS stores successive longwords containing addresses in the object module. Compaq recommends that you use .ADDRESS rather than .LONG for storing address data to provide additional information to the linker. In shareable images, addresses that you specify with .ADDRESS produce position-independent code.

#### Example

```
TABLE: .ADDRESS LAB_4, LAB_3, ROUTTERM ; Reference table
```

## **.ALIGN**

Location counter alignment directive

### **Format**

```
.ALIGN integer[,expression]
.ALIGN keyword[,expression]
```

### **Parameters**

#### **integer**

An integer in the range 0 to 9. The location counter is aligned at an address that is the value of 2 raised to the power of the integer.

#### **keyword**

One of five keywords that specify the alignment boundary. The location counter is aligned to an address that is the next multiple of the following values:

| <b>Keyword</b> | <b>Size (in Bytes)</b> |
|----------------|------------------------|
| BYTE           | 2 <sup>0</sup> = 1     |
| WORD           | 2 <sup>1</sup> = 2     |
| LONG           | 2 <sup>2</sup> = 4     |
| QUAD           | 2 <sup>3</sup> = 8     |
| PAGE           | 2 <sup>9</sup> = 512   |

#### **expression**

Specifies the fill value to be stored in each byte. The expression must not contain any undefined symbols and must be an absolute expression (see Section 3.5).

### **Description**

.ALIGN aligns the location counter to the boundary specified by either an integer or a keyword.

#### **Notes**

1. The alignment that you specify in .ALIGN cannot exceed the alignment of the program section in which the alignment is attempted (see the description of .PSECT). For example, if you are using the default program section alignment (BYTE) and you specify .ALIGN with a word or larger alignment, the assembler displays an error message. fills the bytes skipped by the location counter (if any) with the value of that expression. Otherwise, the assembler fills the bytes with zeros.

## Assembler Directives

### .ALIGN

2. Although most instructions can use byte alignment of data, execution speed is improved by the following alignments:

| Data Length | Alignment |
|-------------|-----------|
| Word        | Word      |
| Longword    | Longword  |
| Quadword    | Quadword  |

### Example

```
.ALIGN BYTE,0      ; Byte alignment--fill with null
.ALIGN WORD        ; Word alignment
.ALIGN 3,^A/ /     ; Quad alignment--fill with blanks
.ALIGN PAGE        ; Page alignment
```

## .ASCIIx

ASCII character storage directives

### Description

VAX MACRO has the following four ASCII character storage directives:

| Directive | Function                               |
|-----------|--|
| ASCIC     | Counted ASCII string storage           |
| ASCID     | String-descriptor ASCII string storage |
| ASCII     | ASCII string storage                   |
| ASCIZ     | Zero-terminated ASCII string storage   |

Each directive is followed by a string of characters enclosed in a pair of matching delimiters. The delimiters can be any printable character except the space or tab character, equal sign (=), semicolon (;), or left angle bracket (<). The character that you use as the delimiter cannot appear in the string itself. Although you can use alphanumeric characters as delimiters, use nonalphanumeric characters to avoid confusion.

Any character except the null, carriage-return, and form-feed characters can appear within the string. The assembler does not convert lowercase alphabetic characters to uppercase.

ASCII character storage directives convert the characters to their 8-bit ASCII value (see Appendix A) and store them one character to a byte.

Any character, including the null, carriage-return, and form-feed characters, can be represented by an expression enclosed in angle brackets (<>) outside of the delimiters. You must define the ASCII values of null, carriage-return, and form-feed with a direct assignment statement. The ASCII character storage directives store the 8-bit binary value specified by the expression.

ASCII strings can be continued over several lines. Use the hyphen (-) as the line continuation character and delimit the string on each line at both ends. Note that you can use a different pair of delimiters for each line. For example:

```
CR=13
LF=10

.ASCII      /ABC DEFG/
.ASCIIZ    @Any character can be a delimiter@
.ASCIC     ? lowercase is not converted to UPPER?
.ASCII     ? this is a test!<CR><KEY>(LF\TEXT)!Isn't it?!
.ASCII     \ Angle Brackets <are part <of> this> string \
.ASCII     / This string is continued / -
           \ on the next line \
.ASCII     <CR><KEY>(LF\TEXT)! this string includes an expression! -
           <128+CR>? whose value is a 13 plus 128?
```

## Assembler Directives

### .ASCIC

---

### .ASCIC

Counted ASCII string storage directive

#### Format

```
.ASCIC string
```

#### Parameter

**string**  
A delimited ASCII string.

#### Description

.ASCIC performs the same function as .ASCII, except that .ASCIC inserts a count byte before the string data. The count byte contains the length of the string in bytes. The length given includes any bytes of nonprintable characters outside the delimited string but excludes the count byte.

.ASCIC is useful in copying text because the count indicates the length of the text to be copied.

#### Example

```
CR=13                                ; Direct assignment statement
                                        ; defines CR
    .ASCIC    #HELLO#<CR>             ; This counted ASCII string
                                        ; is equivalent to the
    .BYTE    6                        ; count followed by
    .ASCII   #HELLO#<CR>             ; the ASCII string
```

## **.ASCID**

String-descriptor ASCII string storage directive

### **Format**

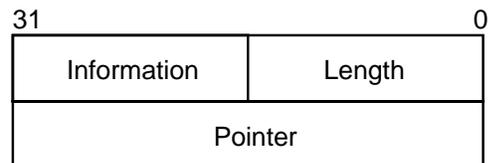
`.ASCID string`

### **Parameter**

**string**  
 A delimited ASCII string.

### **Description**

`.ASCID` performs the same function as `ASCII`, except that `.ASCID` inserts a string descriptor before the string data. The string descriptor has the following format:



ZK-0370-GE

### **Parameters**

**length**  
 The length of the string (2 bytes).

**information**  
 Descriptor information (2 bytes) is always set to 010E.

**pointer**  
 Position-independent pointer to the string (4 bytes).

String descriptors are used in calling procedures (see the *OpenVMS RTL String Manipulation (STRS) Manual*).

### **Example**

```

DESCR1: .ASCID /ARGUMENT FOR CALL/      ; String descriptor
DESCR2: .ASCID /SECOND ARGUMENT/      ; Another string
                                           ; descriptor
      .
      .
      .
      PUSHAL  DESCR1                    ; Put address of descriptors
      PUSHAL  DESCR2                    ; on the stack
      CALLS   #2,STRNG_PROC             ; Call procedure
  
```

## Assembler Directives

### .ASCII

---

### .ASCII

ASCII string storage directive

#### Format

.ASCII string

#### Parameter

**string**

A delimited ASCII string.

#### Description

.ASCII stores the ASCII value of each character in the ASCII string or the value of each byte expression in the next available byte.

#### Example

```
CR=13                                ; Assignment statements
LF=10                                ;   define CR and LF

    .ASCII  "DATE: 17-NOV-1988"      ; Delimiter is "
    .ASCII  /EOF/<CR><LF>            ; Delimiter is /
```

## **.ASCIZ**

Zero-terminated ASCII string storage directive

### **Format**

```
.ASCIZ string
```

### **Parameter**

**string**  
A delimited ASCII string.

### **Description**

**.ASCIZ** performs the same function as **.ASCII**, except that **.ASCIZ** appends a null byte as the final character of the string. When a list or text string is created with an **.ASCIZ** directive, you need only perform a search for the null character in the last byte to determine the end of the string.

### **Example**

```
FF=12                                ; Define FF
    .ASCIZ /ABCDEF/                  ; 6 characters in string,
    .ASCIZ /A/<FF>/B/                ; 7 bytes of data
                                      ; 3 characters in strings
```

## Assembler Directives

### .BLKx

---

### .BLKx

Block storage allocation directives

#### Format

.BLKA expression  
.BLKB expression  
.BLKD expression  
.BLKF expression  
.BLKG expression  
.BLKH expression  
.BLKL expression  
.BLKO expression  
.BLKQ expression  
.BLKW expression

#### Parameter

##### **expression**

An expression specifying the amount of storage to be allocated. All the symbols in the expression must be defined and the expression must be an absolute expression (see Section 3.5). If the expression is omitted, a default value of 1 is assumed.

#### Description

VAX MACRO has the following 10 block storage directives.

| Directive | Function   |
|-----------|--|
| .BLKA     | Reserves storage for addresses (longwords).                            |
| .BLKB     | Reserves storage for byte data.  |
| .BLKD     | Reserves storage for double-precision floating-point data (quadwords). |
| .BLKF     | Reserves storage for single-precision floating-point data (longwords). |
| .BLKG     | Reserves storage for G_floating data (quadwords).                      |
| .BLKH     | Reserves storage for H_floating data (octawords).                      |
| .BLKL     | Reserves storage for longword data.                                    |
| .BLKO     | Reserves storage for octaword data.                                    |
| .BLKQ     | Reserves storage for quadword data.                                    |
| .BLKW     | Reserves storage for word data.  |

Each directive reserves storage for a different data type. The value of the expression determines the number of data items for which VAX MACRO reserves storage. For example, .BLKL 4 reserves storage for 4 longwords of data and .BLKB 2 reserves storage for 2 bytes of data.

The total number of bytes reserved is equal to the length of the data type times the value of the expression as follows:

| Directive | Number of Bytes Allocated |
|-----------|---------------------------|
| .BLKB     | Value of expression       |
| .BLKW     | 2 value of expression     |
| .BLKA     | "                         |
| .BLKF     | 4 value of expression     |
| .BLKL     | "                         |
| .BLKD     | 8 value of expression     |
| .BLKG     | "                         |
| .BLKQ     | "                         |
| .BLKH     | 16 value of expression    |
| .BLKO     | "                         |

### Example

```
.BLKB 15          ; Space for 15 bytes
.BLKO 3           ; Space for 3 octawords (48 bytes)
.BLKL 1           ; Space for 1 longword (4 bytes)
.BLKF <3*4>      ; Space for 12 single-precision
                  ; floating-point values (48 bytes)
```

## Assembler Directives

### .BYTE

---

### .BYTE

Byte storage directive

#### Format

.BYTE expression-list

#### Parameter

##### expression-list

One or more expressions separated by commas (,). Each expression is first evaluated as a longword expression; then the value of the expression is truncated to 1 byte. The value of each expression should be in the range 0 to 255 for unsigned data or in the range -128 to +127 for signed data.

Optionally, each expression can be followed by a repetition factor delimited by square brackets ([ ]). An expression followed by a repetition factor has the following format:

expression1[expression2]

##### expression1

An expression that specifies the value to be stored.

##### [expression2]

An expression that specifies the number of times the value will be repeated. The expression must not contain any undefined symbols and it must be absolute (see Section 3.5). The square brackets are required.

#### Description

.BYTE generates successive bytes of binary data in the object module.

#### Notes

1. The assembler displays an error message if the high-order 3 bytes of the longword expression have a value other than 0 or ^XFFFFFF.
2. At link time, a relocatable expression can result in a value that exceeds 1 byte in length. In this case, the linker issues a truncation diagnostic message for the object module in question. For example:

```
A:      .BYTE  A      ; Relocatable value 'A' will
                ;   cause linker truncation
                ;   diagnostic if the statement
                ;   has a virtual address of 256
                ;   or above
```

3. The .SIGNED\_BYTE directive is the same as .BYTE except that the assembler displays a diagnostic message if a value in the range 128 to 255 is specified. See the description of .SIGNED\_BYTE for more information.

**Example**

```
.BYTE <1024-1000>*2      ; Stores a value of 48
.BYTE ^XA,FIF,10,65-<21*3> ; Stores 4 bytes of data
.BYTE 0                  ; Stores 1 byte of data
.BYTE X,X+3[5*4],Z      ; Stores 22 bytes of data
```

## Assembler Directives

### .CROSS

---

### .CROSS

### .NOCROSS

Cross-reference directives

#### Format

.CROSS [symbol-list]

.NOCROSS [symbol-list]

#### Parameter

##### symbol-list

A list of legal symbol names separated by commas (,).

#### Description

When you specify the /CROSS\_REFERENCE qualifier in the MACRO command, VAX MACRO produces a cross-reference listing. The .CROSS and .NOCROSS directives control which symbols are included in the cross-reference listing. The .CROSS and .NOCROSS directives have an effect only if /CROSS\_REFERENCE was specified in the MACRO command (see the *OpenVMS DCL Dictionary*).

By default, the cross-reference listing includes the definition and all the references to every symbol in the module.

You can disable the cross-reference listing for all symbols or for a specified list of symbols by using .NOCROSS. Using .NOCROSS without a symbol list disables the cross-reference listing of all symbols. Any symbol definition or reference that appears in the code after .NOCROSS used without a symbol list and before the next .CROSS used without a symbol list is excluded from the cross-reference listing. You reenables the cross-reference listing by using .CROSS without a symbol list.

.NOCROSS with a symbol list disables the cross-reference listing for the listed symbols only. .CROSS with a symbol list enables or reenables the cross-reference listing of the listed symbols.

#### Notes

1. The .CROSS directive without a symbol list will not reenables the cross-reference listing of a symbol specified in .NOCROSS with a symbol list.
2. If the cross-reference listing of all symbols is disabled, .CROSS with a symbol list will have no effect until the cross-reference listing is reenables by .CROSS without a symbol list.

## Examples

```
1.      .NOCROSS                ; Stop cross-reference
LAB1:   MOVL      LOC1, LOC2    ; Copy data
       .CROSS                 ; Reenable cross-reference
```

In this example, the definition of LAB1 and the references to LOC1 and LOC2 are not included in the cross-reference listing.

```
2.      .NOCROSS LOC1          ; Do not cross-reference LOC1
LAB2:   MOVL      LOC1,LOC2    ; Copy data
       .CROSS     LOC1        ; Reenable cross-reference
                               ;   of LOC1
```

In this example, the definition of LAB2 and the reference to LOC2 are included in the cross-reference, but the reference to LOC1 is not included in the cross-reference.

## Assembler Directives

### .DEBUG

---

### .DEBUG

Debug symbol attribute directive

#### Format

```
.DEBUG symbol-list
```

#### Parameter

**symbol-list**

A list of legal symbols separated by commas (,).

#### Description

.DEBUG specifies that the symbols in the list are made known to the VAX Symbolic Debugger. During an interactive debugging session, you can use these symbols to refer to memory locations or to examine the values assigned to the symbols.

**Note**

The assembler adds the symbols in the symbol list to the symbol table in the object module. You need not specify global symbols in the .DEBUG directive because global symbols are automatically put in the object module's symbol table. (See the description of .ENABLE for a discussion of how to make information about local symbols available to the debugger.)

#### Example

```
.DEBUG INPUT,OUTPUT,-      ; Make these symbols known  
      LAB_30,LAB_40        ; to the debugger
```

## **.DEFAULT**

Default control directive

### **Format**

`.DEFAULT DISPLACEMENT, keyword`

### **Parameter**

#### **keyword**

One of three keywords—`BYTE`, `WORD`, or `LONG`—indicating the default displacement length.

### **Description**

`.DEFAULT` determines the default displacement length for the relative and relative deferred addressing modes (see Section 5.2.1 and Section 5.2.2).

#### **Notes**

1. The `.DEFAULT` directive has no effect on the default displacement for displacement and displacement deferred addressing modes (see Section 5.1.6 and Section 5.1.7).
2. If there is no `.DEFAULT` in a source module, the default displacement length for the relative and relative deferred addressing modes is a longword.

### **Example**

```
.DEFAULT DISPLACEMENT,WORD ; WORD is default
MOVL LABEL,R1 ; Assembler uses word
; displacement unless
; label has been defined

.DEFAULT DISPLACEMENT,LONG ; LONG is default
INCB @COUNTS+4 ; Assembler uses longword
; displacement unless
; COUNTS has been defined
```

## Assembler Directives

### .D\_FLOATING

---

### .D\_FLOATING

### .DOUBLE

Floating-point storage directive

#### Format

```
.D_FLOATING literal-list  
.DOUBLE literal-list
```

#### Parameter

##### literal-list

A list of floating-point constants (see Section 3.2.2). The constants cannot contain any unary or binary operators except unary plus or unary minus.

#### Description

.D\_FLOATING evaluates the specified floating-point constants and stores the results in the object module. .D\_FLOATING generates 64-bit, double-precision, floating-point data (1 bit of sign, 8 bits of exponent, and 55 bits of fraction). See the description of .F\_FLOATING for information on storing single-precision floating-point numbers and the descriptions of .G\_FLOATING and .H\_FLOATING for descriptions of other floating-point numbers.

#### Notes

1. Double-precision floating-point numbers are always rounded. They are not affected by .ENABLE TRUNCATION.
2. The floating-point constants in the literal list must not be preceded by the floating-point operator (^F).

#### Example

```
.D_FLOATING 1000,1.0E3,1.0000000E-9 ; Constant  
.DOUBLE 3.1415928, 1.107153423828 ; List  
.D_FLOATING 5, 10, 15, 0, 0.5
```

## **.DISABLE**

Function control directive

### **Format**

`.DISABLE argument-list`

### **Parameter**

#### **argument-list**

One or more of the symbolic arguments listed in Table 6–3 in the description of `.ENABLE`. You can use either the long or the short form of the symbolic arguments. If you specify multiple arguments, separate them by commas (`,`), spaces, or tabs.

### **Description**

`.DISABLE` disables the specified assembler functions. See the description of `.ENABLE` for more information.

#### **Note**

The alternate form of `.DISABLE` is `.DSABL`.

## Assembler Directives

### .ENABLE

---

## .ENABLE

Function control directive

### Format

.ENABLE argument-list

### Parameter

#### argument-list

One or more of the symbolic arguments listed in Table 6–3. You can use either the long form or the short form of the symbolic arguments.

If you specify multiple arguments, separate them with commas (,), spaces, or tabs.

**Table 6–3 .ENABLE and .DISABLE Symbolic Arguments**

| Long Form   | Short Form | Default Condition | Function  |
|-------------|------------|-------------------|---|
| ABSOLUTE    | AMA        | Disabled          | When ABSOLUTE is enabled, all the PC relative addressing modes are assembled as absolute addressing modes.  |
| DEBUG       | DBG        | Disabled          | When DEBUG is enabled, all local symbols are included in the object module's symbol table for use by the debugger.  |
| GLOBAL      | GBL        | Enabled           | When GLOBAL is enabled, all undefined symbols are considered external symbols. When GLOBAL is disabled, any undefined symbol that is not listed in an .EXTERNAL directive causes an assembly error.                                   |
| LOCAL_BLOCK | LSB        | Disabled          | When LOCAL_BLOCK is enabled, the current local label block is ended and a new one is started. When LOCAL_BLOCK is disabled, the current local label block is ended. See Section 3.4 for a complete description of local label blocks. |

(continued on next page)

**Table 6–3 (Cont.) .ENABLE and .DISABLE Symbolic Arguments**

| Long Form   | Short Form | Default Condition | Function   |
|-------------|------------|-------------------|--|
| SUPPRESSION | SUP        | Disabled          | When SUPPRESSION is enabled, all symbols that are defined but not referred to are not listed in the symbol table. When SUPPRESSION is disabled, all symbols that are defined are listed in the symbol table.   |
| TRACEBACK   | TBK        | Enabled           | When TRACEBACK is enabled, the program section names and lengths, module names, and routine names are included in the object module for use by the debugger. When TRACEBACK is disabled, VAX MACRO excludes this information and, in addition, does not make any local symbol information available to the debugger. |
| TRUNCATION  | FPT        | Disabled          | When TRUNCATION is enabled, single-precision, floating-point numbers are truncated. When TRUNCATION is disabled, single-precision floating-point numbers are rounded. D_floating, G_floating, and H_floating numbers are not affected by .ENABLE TRUNCATION; they are always rounded.                                |
| VECTOR      |            | Disabled          | When VECTOR is enabled, the assembler accepts and correctly handles vector code. If vector assembly is not enabled, vector code produces assembly errors.  |

## Assembler Directives

### .ENABLE

#### Description

.ENABLE enables the specified assembly function. .ENABLE and its negative form, .DISABLE, control the following assembler functions:

- Creating local label blocks
- Making all local symbols available to the debugger and enabling the traceback feature
- Specifying that undefined symbol references are external references
- Truncating or rounding single-precision floating-point numbers
- Suppressing the listing of symbols that are defined but not referenced
- Specifying that all the PC references are absolute, not relative

#### Note

The alternate form of .ENABLE is .ENABL.

#### Example

```
.ENABLE ABSOLUTE, GLOBAL      ; Assemble relative address mode
                               ; as absolute address mode, and consider
                               ; undefined references as global

.DISABLE TRUNCATION,TRACEBACK ; Round floating-point numbers, and
                               ; omit debugging information from
                               ; the object module
```

## **.END**

Assembly termination directive

### **Format**

`.END [symbol]`

### **Parameter**

**symbol**

The address (called the transfer address) at which program execution is to begin.

### **Description**

`.END` terminates the source program. No additional text should occur beyond this point in the current source file or in any additional source files specified in the command line for this assembly. If any additional text does occur, the assembler ignores it. The additional text does not appear in either the listing file or the object file.

#### **Notes**

1. The transfer address must be in a program section that has the EXE attribute (see the description of `.PSECT`).
2. When an executable image consisting of several object modules is linked, only one object module should be terminated by an `.END` directive that specifies a transfer address. All other object modules should be terminated by `.END` directives that do not specify a transfer address. If an executable image contains either no transfer address or more than one transfer address, the linker displays an error message.
3. If the source program contains an unterminated conditional code block when the `.END` directive is specified, the assembler displays an error message.

### **Example**

```
.ENTRY  START,0           ; Entry mask
.
.                         ; Main program
.
.END    START             ; Transfer address
```

## Assembler Directives

### **.ENDC**

---

### **.ENDC**

End conditional directive

### **Format**

.ENDC

### **Description**

.ENDC terminates the conditional range started by the .IF directive. See the description of .IF for more information and examples.

## **.ENDM**

End definition directive

### **Format**

.ENDM [macro-name]

### **Parameters**

#### **macro-name**

The name of the macro whose definition is to be terminated. The macro name is optional; if specified, it must match the name defined in the matching .MACRO directive. The macro name should be specified so that the assembler can detect any improperly nested macro definitions.

### **Description**

.ENDM terminates the macro definition. See the description of .MACRO for an example of the use of .ENDM.

#### **Note**

If .ENDM is encountered outside a macro definition, the assembler displays an error message.

## Assembler Directives

### **.ENDR**

---

### **.ENDR**

End range directive

### **Format**

.ENDR

### **Description**

.ENDR indicates the end of a repeat range. It must be the final statement of every indefinite repeat block directive (.IRP and .IRPC) and every repeat block directive (.REPEAT). See the description of these directives for examples of the use of .ENDR.

## **.ENTRY**

Entry directive

### **Format**

`.ENTRY symbol,expression`

### **Parameters**

**symbol**

The symbolic name for the entry point.

**expression**

The register save mask for the entry point. The expression must be an absolute expression and must not contain any undefined symbols.

### **Description**

`.ENTRY` defines a symbolic name for an entry point and stores a register save mask (2 bytes) at that location. The symbol is defined as a global symbol with a value equal to the value of the location counter at the `.ENTRY` directive. You can use the entry point as the transfer address of the program. Use the register save mask to determine which registers are saved before the procedure is called. These saved registers are automatically restored when the procedure returns control to the calling program. See the description of the procedure call instructions in Chapter 9.

#### **Notes**

1. The register mask operator (^M) is convenient to use for setting the bits in the register save mask (see Section 3.6.2.2).
2. An assembly error occurs if the expression has bits 0, 1, 12, or 13 set. These bits correspond to the registers R0, R1, AP, and FP and are reserved for the CALL interface.
3. Compaq recommends that you use `.ENTRY` to define all callable entry points including the transfer address of the program. Although the following construct also defines an entry point, Compaq discourages its use:

```
symbol:: .WORD expression
```

Although your program can call a procedure starting with this construct, the entry mask is not checked for any illegal registers, and the symbol cannot be used in a `.MASK` directive.

4. You should use `.ENTRY` only for procedures that are called by the `CALLS` or `CALLG` instruction. A routine that is entered by the `BSB` or `JSB` instruction should not use `.ENTRY` because these instructions do not expect a register save mask. Begin these routines using the following format:

```
symbol:: first instruction
```

The first instruction of the routine immediately follows the symbol.

## Assembler Directives

### .ENTRY

#### Example

```
.ENTRY  CALC, ^M<R2,R3,R7>      ; Procedure starts here.  
                                ; Registers R2, R3, and R7  
                                ; are preserved by CALL  
                                ; and RET instructions
```

## **.ERROR**

Error directive

### **Format**

`.ERROR [expression] ;comment`

### **Parameters**

#### **expression**

An expression whose value is displayed when `.ERROR` is encountered during assembly.

#### **;comment**

A comment that is displayed when `.ERROR` is encountered during assembly. The comment must be preceded by a semicolon (;).

### **Description**

`.ERROR` causes the assembler to display an error message on the terminal or batch log file and in the listing file (if there is one).

#### **Notes**

1. `.ERROR`, `.WARN`, and `.PRINT` are message display directives. Use them to display information indicating that a macro call contains an error or an illegal set of conditions.
2. When the assembly is finished, the assembler displays the total number of errors, warnings, information messages, and the sequence numbers of the lines causing the errors or warnings.
3. If `.ERROR` is included in a macro library, end the comment with a semicolon (;). Otherwise, the librarian will strip the comment from the directive and it will not be displayed when the macro is called.
4. The line containing the `.ERROR` directive is not included in the listing file.
5. If the expression has a value of zero, it is not displayed in the error message.

## Assembler Directives

### .ERROR

#### Example

```
.IF DEFINED    LONG_MESS
. IF GREATER  1000-WORK_AREA
.ERROR 25          ; Need larger WORK_AREA;
.ENDC
.ENDC
```

In this example, if the symbol LONG\_MESS is defined and if the symbol WORK\_AREA has a value of 1000 or less, the following error message is displayed:

```
%MACRO-E-GENERR, Generated ERROR: 25 Need larger WORK_AREA
```

## **.EVEN**

Even location counter alignment directive

### **Format**

.EVEN

### **Description**

.EVEN ensures that the current value of the location counter is even by adding 1 if the current value is odd. If the current value is already even, no action is taken.

## Assembler Directives

### .EXTERNAL

---

### .EXTERNAL

External symbol attribute directive

#### Format

`.EXTERNAL symbol-list`

#### Parameter

##### **symbol-list**

A list of legal symbols, separated by commas (,).

#### Description

`.EXTERNAL` indicates that the specified symbols are external; that is, the symbols are defined in another object module and cannot be defined until link time (see Section 3.3.3 for a discussion of external references).

#### Notes

1. If the `GLOBAL` argument is enabled (see Table 6–3), all unresolved references will be marked as global and external. If `GLOBAL` is enabled, you need not specify `.EXTERNAL`. If `GLOBAL` is disabled, you must explicitly specify `.EXTERNAL` to declare any symbols that are defined externally but are referred to in the current module.
2. If `GLOBAL` is disabled and the assembler finds symbols that are neither defined in the current module nor listed in a `.EXTERNAL` directive, the assembler displays an error message.
3. Note that if your program does not reference, in a relocatable program section, symbols that are declared in the absolute program section (ABS), the unreferenced symbols are filtered out by the assembler and will not be included in the object file. This filtering out will occur even if the symbols are declared global or external.

If you want to be sure that a symbol will be included even if it is not referenced, declare it in a relocatable program section. If you want to make sure that a symbol you define in an absolute program section is included, reference it in a relocatable program section.

4. The alternate form of `.EXTERNAL` is `.EXTRN`.

#### Example

```
.EXTERNAL    SIN,TAN,COS    ; These symbols are defined in
.EXTERNAL    SINH,COSH,TANH ; externally assembled modules
```

---

**.F\_FLOATING**  
**.FLOAT**

Floating-point storage directive

**Format**

.F\_FLOATING literal-list  
.FLOAT literal-list

**Parameter**

**literal-list**

A list of floating-point constants (see Section 3.2.2). The constants cannot contain any unary or binary operators except unary plus and unary minus.

**Description**

.F\_FLOATING evaluates the specified floating-point constants and stores the results in the object module. .F\_FLOATING generates 32-bit, single-precision, floating-point data (1 bit of sign, 8 bits of exponent, and 23 bits of fractional significance). See the description of .D\_FLOATING for information on storing double-precision floating-point numbers and the descriptions of .G\_FLOATING and .H\_FLOATING for descriptions of other floating-point numbers.

**Notes**

1. See the description of .ENABLE for information on specifying floating-point rounding or truncation.
2. The floating-point constants in the literal list must not be preceded by the floating-point unary operator (^F).

**Example**

```
.F_FLOATING 134.5782,74218.34E20 ; Constant list
.F_FLOATING 134.2,0.1342E3,1342E-1 ; These all generate 134.2
.F_FLOATING -0.75,1E38,-1.0E-37 ; Constant list
.FLOAT 0,25,50
```

## Assembler Directives

### **.G\_FLOATING**

---

## **.G\_FLOATING**

G\_floating-point storage directive

### **Format**

```
.G_FLOATING literal-list
```

### **Parameters**

#### **literal-list**

A list of floating-point constants (see Section 3.2.2). The constants cannot contain any unary or binary operators except unary plus or unary minus.

### **Description**

`.G_FLOATING` evaluates the specified floating-point constants and stores the results in the object module. `.G_FLOATING` generates 64-bit data (1 bit of sign, 11 bits of exponent, and 52 bits of fraction).

#### **Notes**

1. G\_floating-point numbers are always rounded. They are not affected by the `.ENABLE TRUNCATION` directive.
2. The floating-point constants in the literal list must not be preceded by the floating-point operator (^F).

### **Example**

```
.G_FLOATING 1000, 1.0E3, 1.0000000E-9 ; Constant list
```

## **.GLOBAL**

Global symbol attribute directive

### **Format**

`.GLOBAL symbol-list`

### **Parameter**

#### **symbol-list**

A list of legal symbol names, separated by commas (,).

### **Description**

`.GLOBAL` indicates that specified symbol names are either globally defined in the current module or externally defined in another module (see Section 3.3.3).

#### **Notes**

1. `.GLOBAL` is provided for MACRO-11 compatibility only. Compaq recommends that global definitions be specified by a double colon (::) or double equal sign (==) (see Section 2.1 and Section 3.8) and that external references be specified by `.EXTERNAL` when necessary.
2. The alternate form of `.GLOBAL` is `.GLOBL`.

### **Example**

```
.GLOBAL LAB_40,LAB_30      ; Make these symbol names
                           ; globally known
.GLOBAL UKN_13             ; to all linked modules
```

## **.H\_FLOATING**

H\_floating-point storage directive

### **Format**

`.H_FLOATING literal-list`

### **Parameter**

#### **literal-list**

A list of floating-point constants (see Section 3.2.2). The constants cannot contain any unary or binary operators except unary plus or unary minus.

### **Description**

`.H_FLOATING` evaluates the specified floating-point constants and stores the results in the object module. `.H_FLOATING` generates 128-bit data (1 bit of sign, 15 bits of exponent, and 112 bits of fraction).

#### **Notes**

1. H\_floating-point numbers are always rounded. They are not affected by the `.ENABLE TRUNCATION` directive.
2. The floating-point constants in the literal list must not be preceded by the floating-point operator (^F).

### **Example**

```
.H_FLOATING 36912, 15.0E18, 1.0000000E-9 ; Constant list
```

## .IDENT

Identification directive

### Format

.IDENT string

### Parameter

#### string

A 1- to 31-character string that identifies the module, such as a string that specifies a version number. The string must be delimited. The delimiters can be any paired printing characters other than the left angle bracket (<) or the semicolon (;), as long as the delimiting character is not contained within the text string.

### Description

.IDENT provides a means of identifying the object module. This identification is in addition to the name assigned to the object module with .TITLE. A character string can be specified in .IDENT to label the object module. This string is printed in the header of the listing file and also appears in the object module.

#### Notes

1. If a source module contains more than one .IDENT, the last directive given establishes the character string that forms part of the object module identification.
2. If the delimiting characters do not match, or if you use an illegal delimiting character, the assembler displays an error message.

### Example

```
.IDENT /3-47/ ; Version and edit numbers
```

The character string “3-47” is included in the object module.

## Assembler Directives

### .IF

---

### .IF

Conditional assembly block directives

#### Format

```
.IF condition argument(s)
```

```
.
```

```
.
```

```
.
```

```
range
```

```
.
```

```
.
```

```
.
```

```
.ENDC
```

#### Parameters

##### **condition**

A specified condition that must be met if the block is to be included in the assembly. The condition must be separated from the argument by a comma (,), space, or tab. Table 6–4 lists the conditions that can be tested by the conditional assembly directives.

##### **argument(s)**

One or more symbolic arguments or expressions of the specified conditional test. If the argument is an expression, it cannot contain any undefined symbols and must be an absolute expression (see Section 3.5).

##### **range**

The block of source code that is conditionally included in the assembly.

**Table 6–4 Condition Tests for Conditional Assembly Directives**

| Condition Test         |            | Complement Condition Test | Argument Type |            | Number of Arguments | Condition that Assembles Block                        |
|------------------------|------------|---------------------------|---------------|------------|---------------------|---|
| Long Form              | Short Form | Long Form                 | Short Form    |            |                     |   |
| EQUAL                  | EQ         | NOT_EQUAL                 | NE            | Expression | 1                   | Expression is equal to 0/not equal to 0.              |
| GREATER                | GT         | LESS_EQUAL                | LE            | Expression | 1                   | Expression is greater than 0/less than or equal to 0. |
| LESS_THAN              | LT         | GREATER_EQUAL             | GE            | Expression | 1                   | Expression is less than 0/greater than or equal to 0. |
| DEFINED                | DF         | NOT_DEFINED               | NDF           | Symbolic   | 1                   | Symbol is defined /not defined.                       |
| BLANK <sup>1</sup>     | B          | NOT_BLANK <sup>1</sup>    | NB            | Macro      | 1                   | Argument is blank/nonblank.                           |
| IDENTICAL <sup>1</sup> | IDN        | DIFFERENT <sup>1</sup>    | DIF           | Macro      | 2                   | Arguments are identical/different.                    |

<sup>1</sup>The BLANK, NOT\_BLANK, IDENTICAL, and DIFFERENT conditions are only useful in macro definitions.

## Description

A conditional assembly block is a series of source statements that is assembled only if a certain condition is met. `.IF` starts the conditional block and `.ENDC` ends the conditional block; each `.IF` must have a corresponding `.ENDC`. The `.IF` directive contains a condition test and one or two arguments. The condition test specified is applied to the arguments. If the test is met, all VAX MACRO statements between `.IF` and `.ENDC` are assembled. If the test is not met, the statements are not assembled. An exception to this rule occurs when you use subconditional directives (see the description of the `.IF_x` directive).

Conditional blocks can be nested; that is, a conditional block can be inside another conditional block. In this case, the statements in the inner conditional block are assembled only if the condition is met for both the outer and inner block.

## Assembler Directives

### .IF

#### Notes

1. If .ENDC occurs outside a conditional assembly block, the assembler displays an error message.
2. VAX MACRO permits a nesting depth of 31 conditional assembly levels. If a statement attempts to exceed this nesting level depth, the assembler displays an error message.
3. Lowercase string arguments are converted to uppercase before being compared, unless the string is surrounded by delimiters. For information on string arguments and delimiters, see Chapter 4.
4. The assembler displays an error message if .IF specifies any of the following: a condition test other than those in Table 6-4, an illegal argument, or a null argument specified in an .IF directive.
5. The .SHOW and .NOSHOW directives control whether condition blocks that are not assembled are included in the listing file.

#### Examples

1. An example of a conditional assembly directive is:

```
.IF EQUAL ALPHA+1      ; Assemble block if ALPHA+1=0. Do
.                       ; not assemble if ALPHA+1 not=0
.
.
.
.ENDC
```

2. Nested conditional directives take the form:

```
.IF condition,argument(s)
. IF condition,argument(s)
.
.
.
.ENDC
.ENDC
```

3. The following conditional directives can govern whether assembly is to occur:

```
.IF DEFINED SYM1
. IF DEFINED SYM2
.
.
.
.ENDC
.ENDC
```

In this example, if the outermost condition is not satisfied, no deeper level of evaluation of nested conditional statements within the program occurs. Therefore, both SYM1 and SYM2 must be defined for the code to be assembled.

## .IF\_x

Subconditional assembly block directives

### Format

```
.IF_FALSE
.IF_TRUE
.IF_TRUE_FALSE
```

### Description

VAX MACRO has the following three subconditional assembly block directives:

| Directive      | Function   |
|----------------|--|
| .IF_FALSE      | If the condition of the assembly block tests false, the program includes the source code following the .IF_FALSE directive and continuing up to the next subconditional directive or to the end of the conditional assembly block.                     |
| .IF_TRUE       | If the condition of the assembly block tests true, the program includes the source code following the .IF_TRUE directive and continuing up to the next subconditional directive or to the end of the conditional assembly block.                       |
| .IF_TRUE_FALSE | Regardless of whether the condition of the assembly block tests true or false, the source code following the .IF_TRUE_FALSE directive (and continuing up to the next subconditional directive or to the end of the assembly block) is always included. |

The implied argument of a subconditional directive is the condition test specified when the conditional assembly block was entered. A conditional or subconditional directive in a nested conditional assembly block is not evaluated if the preceding (or outer) condition in the block is not satisfied (see Examples 3 and 4).

A conditional block with a subconditional directive is different from a nested conditional block. If the condition in the .IF is not met, the inner conditional blocks are not assembled, but a subconditional directive can cause a block to be assembled.

### Notes

1. If a subconditional directive appears outside a conditional assembly block, the assembler displays an error message.
2. The alternate forms of .IF\_FALSE, .IF\_TRUE, and .IF\_TRUE\_FALSE are .IFF, .IFT, and .IFTF.





## Assembler Directives

### .IIF

---

### .IIF

Immediate conditional assembly block directive

#### Format

.IIF condition [,]argument(s), statement

#### Parameters

##### condition

One of the legal condition tests defined for conditional assembly blocks in Table 6–4 (see the description of .IF). The condition must be separated from the arguments by a comma (,), space, or tab. If the first argument can be a blank, the condition must be separated from the arguments with a comma.

##### argument(s)

An expression or symbolic argument (described in Table 6–4) associated with the immediate conditional assembly block directive. If the argument is an expression, it cannot contain any undefined symbols and must be an absolute expression (see Section 3.5). The arguments must be separated from the statement by a comma.

##### statement

The statement to be assembled if the condition is satisfied.

#### Description

.IIF provides a means of writing a one-line conditional assembly block. The condition to be tested and the conditional assembly block are expressed completely within the line containing the .IIF directive. No terminating .ENDC statement is required.

##### Note

The assembler displays an error message if .IIF specifies a condition test other than those listed in Table 6–4, an illegal argument, or a null argument.

#### Example

```
.IIF DEFINED EXAM, BEQL ALPHA
```

This directive generates the following code if the symbol EXAM is defined within the source program:

```
BEQL ALPHA
```

## **.IRP**

Indefinite repeat argument directive

### **Format**

```
.IRP  symbol,<argument list>
```

```
.
```

```
.
```

```
.
```

```
range
```

```
.
```

```
.
```

```
.
```

```
.ENDR
```

### **Parameters**

#### **symbol**

A formal argument that is successively replaced with the specified actual arguments enclosed in angle brackets (<>). If no formal argument is specified, the assembler displays an error message.

#### **<argument list>**

A list of actual arguments enclosed in angle brackets and used in expanding the indefinite repeat range. An actual argument can consist of one or more characters. Multiple arguments must be separated by a legal separator (comma, space, or tab). If no actual arguments are specified, no action is taken.

#### **range**

The block of source text to be repeated once for each occurrence of an actual argument in the list. The range can contain macro definitions and repeat ranges. `.MEXIT` is legal within the range.

### **Description**

`.IRP` replaces a formal argument with successive actual arguments specified in an argument list. This replacement process occurs during the expansion of the indefinite repeat block range. The `.ENDR` directive specifies the end of the range.

`.IRP` is analogous to a macro definition with only one formal argument. At each expansion of the repeat block, this formal argument is replaced with successive elements from the argument list. The directive and its range are coded in line within the source program. This type of macro definition and its range do not require calling the macro by name, as do other macros described in this section.

`.IRP` can appear either inside or outside another macro definition, indefinite repeat block, or repeat block (see the description of `.REPEAT`). The rules for specifying `.IRP` arguments are the same as those for specifying macro arguments.

## Assembler Directives

### .IRP

#### Example

The macro definition is as follows:

```
.MACRO CALL_SUB          SUBR,A1,A2,A3,A4,A5,A6,A7,A8,A9,A10
.NARG COUNT
.IRP ARG,<A10,A9,A8,A7,A6,A5,A4,A3,A2,A1>
.IIF NOT_BLANK , ARG, PUSHL ARG
.ENDR
CALLS #<COUNT-1>,SUBR      ; Note SUBR is counted
.ENDM CALL_SUB
```

The macro call and expansion of the macro defined previously is as follows:

```
CALL_SUB          TEST,INRES,INTES,UNLIS,OUTCON,#205
.NARG COUNT
.IRP ARG,<,,,,,#205,OUTCON,UNLIS,INTES,INRES>
.IIF NOT_BLANK , ARG, PUSHL ARG
.ENDR
.IIF NOT_BLANK , , PUSHL
.IIF NOT_BLANK , #205, PUSHL #205
.IIF NOT_BLANK , OUTCON, PUSHL OUTCON
.IIF NOT_BLANK , UNLIS, PUSHL UNLIS
.IIF NOT_BLANK , INTES, PUSHL INTES
.IIF NOT_BLANK , INRES, PUSHL INRES
CALLS #<COUNT-1>,TEST      ; Note TEST is counted
```

This example uses the .NARG directive to count the arguments and the .IIF NOT\_BLANK directive (see descriptions of .IF and .IIF in this section) to determine whether the actual argument is blank. If the argument is blank, no binary code is generated.

---

## **.IRPC**

Indefinite repeat character directive

### **Format**

```
.IRPC symbol,<STRING>
```

```
.
```

```
.
```

```
.
```

```
range
```

```
.
```

```
.
```

```
.
```

```
.ENDR
```

### **Parameters**

#### **symbol**

A formal argument that is successively replaced with the specified characters enclosed in angle brackets (<>). If no formal argument is specified, the assembler displays an error message.

#### **<STRING>**

A sequence of characters enclosed in angle brackets and used in the expansion of the indefinite repeat range. Although the angle brackets are required only when the string contains separating characters, their use is recommended for legibility.

#### **range**

The block of source text to be repeated once for each occurrence of a character in the list. The range can contain macro definitions and repeat ranges. `.MEXIT` is legal within the range.

### **Description**

`.IRPC` is similar to `.IRP` except that `.IRPC` permits single-character substitution rather than argument substitution. On each iteration of the indefinite repeat range, the formal argument is replaced with each successive character in the specified string. The `.ENDR` directive specifies the end of the range.

`.IRPC` is analogous to a macro definition with only one formal argument. At each expansion of the repeat block, this formal argument is replaced with successive characters from the actual argument string. The directive and its range are coded in line within the source program and do not require calling the macro by name.

`.IRPC` can appear either inside or outside another macro definition, indefinite repeat block, or repeat block (see description of `.REPEAT`).

## Assembler Directives

### .IRPC

### Example

The macro definition is as follows:

```
        .MACRO  HASH_SYM          SYMBOL
        .NCHR   HV, <SYMBOL>
        .IRPC   CHR, <SYMBOL>
HV = HV+^A?CHR?
        .ENDR
        .ENDM   HASH_SYM
```

The macro call and expansion of the macro defined previously is as follows:

```
        HASH_SYM      <MOVC5>
        .NCHR   HV, <MOVC5>
        .IRPC   CHR, <MOVC5>
HV = HV+^A?CHR?
        .ENDR
HV = HV+^A?M?
HV = HV+^A?O?
HV = HV+^A?V?
HV = HV+^A?C?
HV = HV+^A?5?
```

This example uses the .NCHR directive to count the number of characters in an actual argument.

---

## .LIBRARY

Macro library directive

### Format

```
.LIBRARY macro-library-name
```

### Parameters

**macro-library-name**

A delimited string that is the file specification of a macro library.

### Description

.LIBRARY adds a name to the macro library list that is searched whenever a .MCALL or an undefined opcode is encountered. The libraries are searched in the reverse order in which they were specified to the assembler.

If you omit any information from the macro-library-name argument, default values are assumed. The device defaults to your current default disk; the directory defaults to your current default directory; the file type defaults to MLB.

Compaq recommends that libraries be specified in the MACRO command line with the /LIBRARY qualifier rather than with the .LIBRARY directive. The .LIBRARY directive makes moving files cumbersome.

### Example

```
.LIBRARY /DISK:[TEST]USERM/ ; DISK:[TEST]USERM.MLB  
.LIBRARY ?DISK:SYSDEF.MLB? ; DISK:SYSDEF.MLB  
.LIBRARY \CURRENT.MLB\ ; Uses default disk and directory
```

## Assembler Directives

### .LINK

---

### .LINK

Linker option record directive

#### Format

```
.LINK "file-spec" [/qualifier[=(module-name[,...]),...]]
```

#### Parameters

##### **file-spec[,...]**

A delimited string that specifies one or more input files. The delimiters can be any matching pair of printable characters except the space, tab, equal sign (=), semicolon (;), or left angle bracket (<). The character that you use as the delimiter cannot appear in the string itself. Although you can use alphanumeric characters as delimiters, use nonalphanumeric characters to avoid confusion.

The input files can be object modules to be linked, or shareable images to be included in the output image. Input files can also be libraries containing external references or specific modules for inclusion in the output image. The linker will search the libraries for the external references. If you specify multiple input files, separate the file specifications with commas (,).

If you do not specify a file type in an input file specification, the linker supplies default file types, based on the nature of the file. All object modules are assumed to have file types of OBJ.

Note that the input file specifications must be correct at *link* time. Make your references explicit, so that if the object module created by VAX MACRO is linked in a directory other than the one in which it was created, the linker will still be able to find the files referenced in the .LINK directive.

No wildcard characters are allowed in the file specification.

#### File Qualifiers

##### **/INCLUDE=(module-name[,...])**

Indicates that the associated input file is an object library or shareable image library, and that only the module names specified are to be unconditionally included as input to the linker.

At least one module name must be specified. If you specify more than one module name, separate the names with commas (,) and enclose the list in parentheses.

No wildcard characters are allowed in the module name specifications. Module names may not be longer than 31 characters, the maximum length of a VAX MACRO symbol.

##### **/LIBRARY**

Indicates that the associated input file is a library to be searched for modules to resolve any undefined symbols in the input files.

If the associated input file specification does not include a file type, the linker assumes the default file type of OLB. You can use both /INCLUDE and /LIBRARY to qualify a file specification. If you specify both /INCLUDE and /LIBRARY, the library is subsequently searched for unresolved references. In this case, the explicit inclusion of modules occurs first; then the linker searches the library for unresolved references.

**/SELECTIVE\_SEARCH**

Directs the linker to add to its symbol table only those global symbols that are defined in the specified file and are currently unresolved. If /SELECTIVE\_SEARCH is not specified, the linker includes all symbols from that file in its global symbol table.

**/SHAREABLE**

Requests that the linker include a shareable image file. No wildcard characters are allowed in the file specification.

The following table contains the abbreviations of the qualifiers for the .LINK directive. Note that to ensure readability, as well as compatibility with future releases, it is recommended that you use the full names of the qualifiers.

| Abbreviation | Qualifier         |
|--------------|-------------------|
| /I           | /INCLUDE          |
| /L           | /LIBRARY          |
| /SE          | /SELECTIVE_SEARCH |
| /SH          | /SHAREABLE        |

**Description**

The .LINK directive allows you to include linker option records in an object module produced by VAX MACRO. The qualifiers for the .LINK directive perform functions similar to the functions performed by the same qualifiers for the DCL command LINK.

You should use the .LINK directive for references that are not linker defaults, but that you always want to include in a particular image. Using the .LINK directive enables you to avoid having to explicitly name these references in the DCL command LINK.

For detailed information on the qualifiers to the DCL command LINK, see the *OpenVMS DCL Dictionary*. For a complete discussion of the operation of the linker itself, see the *OpenVMS Linker Utility Manual*.

**Examples**

1. `.LINK "SYS$LIBRARY:MYLIB" /INCLUDE=(MOD1, MOD2, MOD6)`

This statement, when included in the file MYPROG.MAR, causes the assembler to request that MYPROG.OBJ be linked with modules MOD1, MOD2, and MOD6 in the library SYS\$LIBRARY:MYLIB.OLB (where SYS\$LIBRARY is a logical name for the disk and directory in which MYLIB.OLB is listed). The library is not searched for other unresolved references. The statement is equivalent to linking the file with the DCL command:

2. `$ LINK MYPROG, SYS$LIBRARY:MYLIB /INCLUDE=(MOD1, MOD2, MOD6)`

## Assembler Directives

### .LINK

```
3. .LINK \SYS$LIBRARY:MYOBJ\           ; Link with object module
                                       ;   SYS$LIBRARY:MYOBJ.OBJ

   .LINK 'SYS$LIBRARY:YOURLIB' /LIBRARY ; Search object library
                                       ;   SYS$LIBRARY:YOURLIB.OLB
                                       ;   for unresolved references

   .LINK *SYS$LIBRARY:MYSTB.STB* /SELECTIVE_SEARCH ; Search symbol table
                                       ;   SYS$LIBRARY:MYSTB.STB
                                       ;   for unresolved references

   .LINK "SYS$LIBRARY:MYSHR.EXE" /SHAREABLE ; Link with shareable image
                                       ;   SYS$LIBRARY:MYSHR.EXE
```

To increase efficiency and performance, include several related input files in a single .LINK directive. The following example shows how the five options illustrated previously can be included in one statement:

```
4. .LINK 'SYS$LIBRARY:MYOBJ',-
      'SYS$LIBRARY:YOURLIB' /LIBRARY,-
      'SYS$LIBRARY:MYLIB' /INCLUDE=(MOD1, MOD2, MOD6),-
      'SYS$LIBRARY:MYSTB.STB' /SELECTIVE_SEARCH,-
      'SYS$LIBRARY:MYSHR.EXE' /SHAREABLE
```

## **.LIST**

Listing directive

### **Format**

.LIST [argument-list]

### **Parameter**

#### **argument-list**

One or more of the symbolic arguments defined in Table 6–8. You can use either the long form or the short form of the arguments. If multiple arguments are specified, separate them with commas (,), spaces, or tabs.

### **Description**

.LIST is equivalent to .SHOW. See the description of .SHOW for more information.

## Assembler Directives

### .LONG

---

### .LONG

Longword storage directive

#### Format

.LONG expression-list

#### Parameters

##### expression-list

One or more expressions separated by commas (,). You have the option of following each expression with a repetition factor delimited by square brackets ([]).

An expression followed by a repetition factor has the format:

expression1[expression2]

##### expression1

An expression that specifies the value to be stored.

##### [expression2]

An expression that specifies the number of times the value is repeated. The expression must not contain any undefined symbols and must be an absolute expression (see Section 3.5). The square brackets are required.

#### Description

.LONG generates successive longwords (4 bytes) of data in the object module.

#### Example

```
LAB_3: .LONG  LAB_3,^X7FFFFFFF,^A'ABCD' ; 3 longwords of data
       .LONG  ^XF@4                      ; 1 longword of data
       .LONG  0[22]                      ; 22 longwords of data
```

#### Note

Each expression in the list must have a value that can be represented in 32 bits.

---

## .MACRO

Macro definition directive

### Format

```
.MACRO macro-name [formal-argument-list]
```

```
.
```

```
.
```

```
.
```

```
range
```

```
.
```

```
.
```

```
.
```

```
.ENDM [macro name]
```

### Parameters

#### **macro-name**

The name of the macro to be defined; this name can be any legal symbol up to 31 characters long.

#### **formal-argument-list**

The symbols, separated by commas (,), to be replaced by the actual arguments in the macro call.

#### **range**

The source text to be included in the macro expansion.

### Description

.MACRO begins the definition of a macro. It gives the macro name and a list of formal arguments (see Chapter 4). If the name specified is the same as the name of a previously defined macro, the previous definition is deleted and replaced with the new one. The .MACRO directive is followed by the source text to be included in the macro expansion. The .ENDM directive specifies the end of the range.

Macro names do not conflict with user-defined symbols. Both a macro and a user-defined symbol can have the same name.

When the assembler encounters a .MACRO directive, it adds the macro name to its macro name table and stores the source text of the macro (up to the matching .ENDM directive). No other processing occurs until the macro is expanded.

The symbols in the formal argument list are associated with the macro name and are limited to the scope of the definition of that macro. For this reason, the symbols that appear in the formal argument list can also appear elsewhere in the program.

## Assembler Directives

### .MACRO

#### Notes

1. If a macro has the same name as a VAX opcode, the macro is used instead of the instruction. This feature allows you to temporarily redefine an opcode.
2. If a macro has the same name as a VAX opcode and is in a macro library, you must use the .MCALL directive to define the macro. Otherwise, because the symbol is already defined (as the opcode), the assembler will not search the macro libraries.
3. You can redefine a macro with new source text during assembly by specifying a second .MACRO directive with the same name. Including a second .MACRO directive within the original macro definition causes the first macro call to redefine the macro. This feature is useful when a macro performs initialization or defines symbols, when an operation is performed only once. The macro redefinition can eliminate unneeded source text in a macro or it can delete the entire macro. The .MDELETE directive provides another way to delete macros.

#### Example

The macro definition is as follows:

```
.MACRO USERDEF
.PSECT DEFIES,ABS
MYSYM= 5
HIVAL= ^XFFF123
LOWVAL= 0
.PSECT RWDATA,NOEXE,LONG
TABLE: .BLKL 100
LIST: .BLKB 10
.MACRO USERDEF ; Redefine it to null
.ENDM USERDEF
.ENDM USERDEF
```

The macro calls and expansions of the macro defined previously are as follows:

```
USERDEF ; Should expand data
.PSECT DEFIES,ABS
MYSYM= 5
HIVAL= ^XFFF123
LOWVAL= 0
.PSECT RWDATA,NOEXE,LONG
TABLE: .BLKL 100
LIST: .BLKB 10
.MACRO USERDEF ; Redefine it to null
.ENDM USERDEF

USERDEF ; Should expand nothing
```

In this example, when the macro is called the first time, it defines some symbols and data storage areas and then redefines itself. When the macro is called a second time, the macro expansion contains no source text.

## **.MASK**

Mask directive

### **Format**

`.MASK symbol[,expression]`

### **Parameters**

**symbol**

A symbol defined in an `.ENTRY` directive.

**expression**

A register save mask.

### **Description**

`.MASK` reserves a word for a register save mask for a transfer vector. See the description of `.TRANSFER` for more information and for an example of `.MASK`.

#### **Notes**

1. If `.MASK` does not contain an expression, the assembler directs the linker to copy the register save mask specified in `.ENTRY` to the word reserved by `.MASK`.
2. If `.MASK` contains an expression, the assembler directs the linker to combine this expression with the register save mask specified in `.ENTRY` and store the result in the word reserved by `.MASK`. The linker performs an inclusive OR operation to combine the mask in the entry point and the value of the expression. Consequently, a register specified in either `.ENTRY` or `.MASK` will be included in the combined mask. See the description of `.ENTRY` for more information on entry masks.

## Assembler Directives

### .MCALL

---

### .MCALL

Macro call directive

#### Format

.MCALL macro-name-list

#### Parameters

##### **macro-name-list**

A list of macros to be defined for this assembly. Separate the macro names with commas (,).

#### Description

.MCALL specifies the names of the system and user-defined macros that are required to assemble the source program but are not defined in the source file.

If any named macro is not found upon completion of the search (that is, if the macro is not defined in any of the macro libraries), the assembler displays an error message.

---

#### Note

---

.MCALL is provided for compatibility with MACRO-11; with one exception, Compaq recommends that you not use it. When VAX MACRO finds an unknown symbol in the opcode field, it automatically searches all macro libraries. If it finds the symbol in a library, it uses the macro definition and expands the macro reference. If VAX MACRO does not find the symbol in the library, it displays an error message.

You must use .MCALL when a macro has the same name as an opcode (see description of .MACRO).

---

#### Example

```
.MCALL  INSQUE          ; Substitute macro in
                          ;   library for INSQUE
                          ;   instruction
```

## **.MDELETE**

Macro deletion directive

### **Format**

```
.MDELETE macro-name-list
```

### **Parameters**

**macro-name-list**

A list of macros whose definitions are to be deleted. Separate the names with commas (,).

### **Description**

.MDELETE deletes the definitions of specified macros. The number of macros actually deleted is printed in the assembly listing on the same line as the .MDELETE directive.

.MDELETE completely deletes the macro, freeing memory as necessary. Macro redefinition with .MACRO merely redefines the macro.

### **Example**

```
.MDELETE USERDEF,$SSDEF,ALTR
```



## **.NARG**

Number of arguments directive

### **Format**

`.NARG symbol`

### **Parameters**

#### **symbol**

A symbol that is assigned a value equal to the number of arguments in the macro call.

### **Description**

`.NARG` determines the number of arguments in the current macro call.

`.NARG` counts all the positional arguments specified in the macro call, including null arguments (specified by adjacent commas (,)). The value assigned to the specified symbol does not include either any keyword arguments or any formal arguments that have default values.

#### **Note**

If `.NARG` appears outside a macro, the assembler displays an error message.

### **Example**

The macro definition is as follows:

```
.MACRO CNT_ARG A1,A2,A3,A4,A5,A6,A7,A8,A9=DEF9,A10=DEF10
.NARG COUNTER      ; COUNTER is set to no. of ARGS
.WORD COUNTER      ; Store value of COUNTER
.ENDM CNT_ARG
```

The macro calls and expansions of the macro defined previously are as follows:

```
CNT_ARG TEST,FIND,ANS      ; COUNTER will = 3
.NARG COUNTER              ; COUNTER is set to no. of ARGS
.WORD COUNTER              ; Store value of COUNTER

CNT_ARG                    ; COUNTER will = 0
.NARG COUNTER              ; COUNTER is set to no. of ARGS
.WORD COUNTER              ; Store value of COUNTER

CNT_ARG TEST,A2=SYMB2,A3=SY3      ; COUNTER will = 1
.NARG COUNTER              ; COUNTER is set to no. of ARGS
.WORD COUNTER              ; Store value of COUNTER
                           ; Keyword arguments are not counted

CNT_ARG ,SYMBL,,           ; COUNTER will = 3
.NARG COUNTER              ; COUNTER is set to no. of ARGS
.WORD COUNTER              ; Store value of COUNTER
                           ; Null arguments are counted
```

## Assembler Directives

### .NCHR

---

### .NCHR

Number of characters directive

#### Format

.NCHR symbol,<string>

#### Parameters

##### symbol

A symbol that is assigned a value equal to the number of characters in the specified character string.

##### <string>

A sequence of printable characters. Delimit the character string with angle brackets (<>) (or a character preceded by a circumflex (^)) only if the specified character string contains a legal separator (comma (,), space, and/or tab) or a semicolon (;).

#### Description

.NCHR determines the number of characters in a specified character string. It can appear anywhere in a VAX MACRO program and is useful in calculating the length of macro arguments.

#### Example

The macro definition is as follows:

```
.MACRO CHAR MESS ; Define MACRO
.NCHR CHRCNT,<MESS> ; Assign value to CHRCNT
.WORD CHRCNT ; Store value
.ASCII /MESS/ ; Store characters
.ENDM CHAR ; Finish
```

The macro calls and expansions of the macro defined previously are as follows:

```
CHAR <HELLO> ; CHRCNT will = 5
.NCHR CHRCNT,<HELLO> ; Assign value to CHRCNT
.WORD CHRCNT ; Store value
.ASCII /HELLO/ ; Store characters

CHAR <14, 75.39 4> ; CHRCNT will = 12(dec)
.NCHR CHRCNT,<14, 75.39 4> ; Assign value to CHRCNT
.WORD CHRCNT ; Store value
.ASCII /14, 75.39 4/ ; Store characters
```

## **.NLIST**

Listing directive

### **Format**

.NLIST [argument-list]

### **Parameter**

#### **argument-list**

One or more of the symbolic arguments listed in Table 6–8. Use either the long form or the short form of the arguments. If you specify multiple arguments, separate them with commas (,), spaces, or tabs.

### **Description**

.NLIST is equivalent to .NOSHOW. See the description of .SHOW for more information.

## Assembler Directives

### **.NOCROSS**

---

### **.NOCROSS**

Cross-reference directive

#### **Format**

`.NOCROSS [symbol-list]`

#### **Parameter**

**symbol-list**

A list of legal symbol names separated by commas (,).

#### **Description**

VAX MACRO produces a cross-reference listing when the `/CROSS_REFERENCE` qualifier is specified in the `MACRO` command. The `.CROSS` and `.NOCROSS` directives control which symbols are included in the cross-reference listing. The description of `.NOCROSS` is included with the description of `.CROSS`.

## **.NOSHOW**

Listing directive

### **Format**

`.NOSHOW [argument-list]`

### **Parameter**

#### **argument-list**

One or more of the symbolic arguments listed in Table 6–8 in the description of `.SHOW`. Use either the long form or the short form of the arguments. If you specify multiple arguments, separate them with commas (,), spaces, or tabs.

### **Description**

`.NOSHOW` specifies listing control options. See the description of `.SHOW` for more information.

## Assembler Directives

### .NTYPE

---

### .NTYPE

Operand type directive

#### Format

.NTYPE symbol,operand

#### Parameters

##### **symbol**

Any legal VAX MACRO symbol. This symbol is assigned a value equal to the 8- or 16-bit addressing mode of the operand argument that follows.

##### **operand**

Any legal address expression, as you use it with an opcode. If no argument is specified, zero is assumed.

#### Description

.NTYPE determines the addressing mode of the specified operand.

The value of the symbol is set to the specified addressing mode. In most cases, an 8-bit (1-byte) value is returned. Bits 0 to 3 specify the register associated with the mode, and bits 4 to 7 specify the addressing mode. To provide concise addressing information, the mode bits 4 to 7 are not exactly the same as the numeric value of the addressing mode described in Table C-6. Literal mode is indicated by a zero in bits 4 to 7, instead of the values 0 to 3. Mode 1 indicates an immediate mode operand, mode 2 indicates an absolute mode operand, and mode 3 indicates a general mode operand.

For indexed addressing mode, a 16-bit (2-byte) value is returned. The high-order byte contains the addressing mode of the base operand specifier and the low-order byte contains the addressing mode of the primary operand (the index register).

See Chapter 5 of this volume for more information on addressing modes.

## Example

```

; The following macro is used to push an address on the stack. It checks
; the operand type (by using .NTYPE) to determine if the operand is an
; address and, if not, the macro simply pushes the argument on the stack
; and generates a warning message.
;
        .MACRO  PUSHADR #ADDR
        .NTYPE  A,ADDR           ; Assign operand type to 'A'
A = A@-4&^XF                    ; Isolate addressing mode
        .IF IDENTICAL 0,<ADDR>  ; Is argument exactly 0?
        PUSHL  #0               ; Stack zero
        .MEXIT                  ; Exit from macro
        .ENDC
ERR = 0                            ; ERR tells if mode is address
                                   ; ERR = 0 if address, 1 if not
        .IIF LESS_EQUAL A-1,    ERR=1 ; Is mode not literal or immediate?
        .IIF EQUAL A-5,        ERR=1  ; Is mode not register?
        .IF EQUAL ERR          ; Is mode address?
        PUSHAL  ADDR           ; Yes, stack address
        .IFF                      ; No
        PUSHL  ADDR           ; Then stack operand & warn
        .WARN   ; ADDR is not an address;
        .ENDC
        .ENDM  PUSHADR

```

The macro calls and expansions of the macro defined previously are as follows:

```

        PUSHADR (R0)           ; Valid argument
        PUSHAL  (R0)           ; Yes, stack address

        PUSHADR (R1)[R4]      ; Valid argument
        PUSHAL  (R1)[R4]      ; Yes, stack address

        PUSHADR 0              ; Is zero
        PUSHL  #0             ; Stack zero

        PUSHADR #1            ; Not an address
        PUSHL  #1            ; Then stack operand & warn
%MACRO-W-GENWRN, Generated WARNING: #1 is not an address

        PUSHADR R0            ; Not an address
        PUSHL  R0            ; Then stack operand & warn
%MACRO-W-GENWRN, Generated WARNING: R0 is not an address

```

Note that to save space, this example is listed as it would appear if **.SHOW BINARY**, not **.SHOW EXPANSIONS**, were specified in the source program.

## Assembler Directives

### .OCTA

---

### .OCTA

Octaword storage directive

#### Format

.OCTA literal

.OCTA symbol

#### Parameters

##### literal

Any constant value. This value can be preceded by ^O, ^B, ^X, or ^D to specify the radix as octal, binary, hexadecimal, or decimal, respectively; or it can be preceded by ^A to specify ASCII text. Decimal is the default radix.

##### symbol

A symbol defined elsewhere in the program. This symbol results in a sign-extended, 32-bit value being stored in an octaword.

#### Description

.OCTA generates 128 bits (16 bytes) of binary data.

##### Note

.OCTA is like .QUAD and unlike other data storage directives (.BYTE, .WORD, and .LONG), in that it does not evaluate expressions and that it accepts only one value. It does not accept a list.

#### Example

```
.OCTA ^A"FEDCBA987654321"      ; Each ASCII character
                                ; is stored in a byte
.OCTA 0                          ; OCTA 0
.OCTA ^X01234ABCD5678F9        ; OCTA hex value specified
.OCTA VINTERVAL                 ; VINTERVAL has 32-bit value,
                                ; sign-extended
```

## **.ODD**

Odd location counter alignment directive

### **Format**

.ODD

### **Description**

.ODD ensures that the current value of the location counter is odd by adding 1 if the current value is even. If the current value is already odd, no action is taken.

## Assembler Directives

### .OPDEF

---

### .OPDEF

Opcode definition directive

#### Format

.OPDEF opcode value,operand-descriptor-list

#### Parameters

##### opcode

An ASCII string specifying the name of the opcode. The string can be up to 31 characters long and can contain the letters A to Z, the digits 0 to 9, and the special characters underscore (`_`), dollar sign (`$`), and period (`.`). The string should not start with a digit and should not be surrounded by delimiters.

##### value

An expression that specifies the value of the opcode. The expression must be absolute and must not contain any undefined values (see Section 3.5). The value of the expression must be in the range 0 to  $65,535_{10}$  (hexadecimal FFFF), but you cannot use the values 252 to 255 because the architecture specifies these as the start of a 2-byte opcode. The expression is represented as follows:

If  $0 < \text{expression} < 251$

Expression is a 1-byte opcode.

If  $\text{expression} > 255$

Expression bits 7:0 are the first byte of the opcode and expression bits 15:8 are the second byte of the opcode.

##### operand-descriptor-list

A list of operand descriptors that specifies the number of operands and the type of each. Up to 16 operand descriptors are allowed in the list. Table 6–5 lists the operand descriptors.

**Table 6–5 Operand Descriptors**

| Access Type | Data Type |      |           |                 |                        |                   |                   |           |           |
|-------------|-----------|------|-----------|-----------------|------------------------|-------------------|-------------------|-----------|-----------|
|             | Byte      | Word | Long-word | Float-ing Point | Double Float-ing Point | G_ Floating Point | H_ Floating Point | Quad-word | Octa-word |
| Address     | AB        | AW   | AL        | AF              | AD                     | AG                | AH                | AQ        | AO        |
| Read-only   | RB        | RW   | RL        | RF              | RD                     | RG                | RH                | RQ        | RO        |
| Modify      | MB        | MW   | ML        | MF              | MD                     | MG                | MH                | MQ        | MO        |
| Write-only  | WB        | WW   | WL        | WF              | WD                     | WG                | WH                | WQ        | WO        |
| Field       | VB        | VW   | VL        | VF              | VD                     | VG                | VH                | VQ        | VO        |
| Branch      | BB        | BW   | —         | —               | —                      | —                 | —                 | —         | —         |

## Description

.OPDEF defines an opcode, which is inserted into a user-defined opcode table. The assembler searches this table before it searches the permanent symbol table. This directive can redefine an existing opcode name or create a new one.

### Notes

1. You can also use a macro to redefine an opcode (see the description of .MACRO in this section). Note that the macro name table is searched before the user-defined opcode table.
2. .OPDEF is useful in creating “custom” instructions that execute user-written microcode. This directive is supplied to allow you to execute your microcode in a MACRO program.
3. The operand descriptors are specified in a format similar to the operand specifier notation described in Chapter 8. The first character specifies the operand access type, and the second character specifies the operand data type.

## Example

```
.OPDEF  MOVL3  ^XA9FF,RL,ML,WL      ; Defines an instruction
                                           ; MOVL3, which uses
                                           ; the reserved opcode FF
.OPDEF  DIVF2  ^X46,RF,MF          ; Redefines the DIVF2 and
.OPDEF  MOVC5  ^X2C,RW,AB,AB,RW,AB ; MOVC5 instructions
.OPDEF  CALL   ^X10,BB             ; Equivalent to a BSBB
```

## Assembler Directives

### .PACKED

---

### .PACKED

Packed decimal string storage directive

#### Format

```
.PACKED decimal-string[,symbol]
```

#### Parameters

##### **decimal-string**

A decimal number from 0 to 31 digits long with an optional sign. Digits can be in the range 0 to 9 (see Section 8.3.14).

##### **symbol**

An optional symbol that is assigned a value equivalent to the number of decimal digits in the string. The sign is not counted as a digit.

#### Description

.PACKED generates packed decimal data, two digits per byte. Packed decimal data is useful in calculations requiring exact accuracy. Packed decimal data is operated on by the decimal string instructions. See Section 8.3.14 for more information on the format of packed decimal data.

#### Example

```
.PACKED -12,PACK_SIZE      ; PACK_SIZE gets value of 2  
.PACKED +500  
.PACKED 0  
.PACKED -0,SUM_SIZE       ; SUM_SIZE gets value of 1
```

## **.PAGE**

Page ejection directive

### **Format**

.PAGE

### **Description**

.PAGE forces a new page in the listing. The directive itself is not printed in the listing.

VAX MACRO ignores .PAGE in a macro definition. The paging operation is performed only during macro expansion.

## Assembler Directives

### .PRINT

---

### .PRINT

Assembly message directive

#### Format

```
.PRINT [expression] ;comment
```

#### Parameters

##### **expression**

An expression whose value is displayed when .PRINT is encountered during assembly.

##### **;comment**

A comment that is displayed when .PRINT is encountered during assembly. The comment must be preceded by a semicolon (;).

#### Description

.PRINT causes the assembler to display an informational message. The message consists of the value of the expression and the comment specified in the .PRINT directive. The message is displayed on the terminal for interactive jobs and in the log file for batch jobs. The message produced by .PRINT is not considered an error or warning message.

#### Notes

1. .PRINT, .ERROR, and .WARN are called the message display directives. You can use these to display information indicating that a macro call contains an error or an illegal set of conditions.
2. If .PRINT is included in a macro library, end the comment with an additional semicolon. If you omit the semicolon, the comment will be stripped from the directive and will not be displayed when the macro is called.
3. If the expression has a value of zero, it is not displayed with the message.

#### Example

```
.PRINT 2 ; The sine routine has been changed
```

## **.PSECT**

Program sectioning directive

### **Format**

`.PSECT [program-section-name[,argument-list]]`

### **Parameters**

#### **program-section-name**

The name of the program section. This name can be up to 31 characters long and can contain any alphanumeric character and the special characters underscore (`_`), dollar sign (`$`), and period (`.`). The first character must not be a digit.

#### **argument-list**

A list containing the program section attributes and the program section alignment. Table 6–6 lists the attributes and their functions. Table 6–7 lists the default attributes and their opposites. Program sections are aligned when you specify an integer in the range 0 to 9 or one of the five keywords listed in the following table. If you specify an integer, the program section is linked to begin at the next virtual address, which is a multiple of 2 raised to the power of the integer. If you specify a keyword, the program section is linked to begin at the next virtual address (a multiple of the values listed in the following table):

| <b>Keyword</b> | <b>Size (in Bytes)</b> |
|----------------|------------------------|
| BYTE           | $2^0 = 1$              |
| WORD           | $2^1 = 2$              |
| LONG           | $2^2 = 4$              |
| QUAD           | $2^3 = 8$              |
| PAGE           | $2^9 = 512$            |

BYTE is the default.

**Table 6–6 Program Section Attributes**

| <b>Attribute</b> | <b>Function</b>  |
|------------------|--|
| ABS              | Absolute—The linker assigns the program section an absolute address. The contents of the program section can be only symbol definitions (usually definitions of symbolic offsets to data structures that are used by the routines being assembled). No data allocations can be made. An absolute program section contributes no binary code to the image, so its byte allocation request to the linker is zero. The size of the data structure being defined is the size of the absolute program section printed in the “program section synopsis” at the end of the listing. Compare this attribute with its opposite, REL. |

(continued on next page)

## Assembler Directives

### .PSECT

Table 6–6 (Cont.) Program Section Attributes

| Attribute | Function   |
|-----------|--|
| CON       | Concatenate—Program sections with the same name and attributes (including CON) are merged into one program section. Their contents are merged in the order in which the linker acquires them. The allocated virtual address space is the sum of the individual requested allocations.  |
| EXE       | Executable—The program section contains instructions. This attribute provides the capability of separating instructions from read-only and read/write data. The linker uses this attribute in gathering program sections and in verifying that the transfer address is in an executable program section.   |
| GBL       | Global—Program sections that have the same name and attributes, including GBL and OVR, will have the same relocatable address in memory even when the program sections are in different clusters (see the <i>OpenVMS Linker Utility Manual</i> for more information on clusters). This attribute is specified for FORTRAN COMMON block program sections (see the <i>VAX FORTRAN User's Guide</i> ). Compare this attribute with its opposite, LCL. |
| LCL       | Local—The program section is restricted to its cluster. Compare this attribute with its opposite, GBL.   |
| LIB       | Library Segment—Reserved for future use.   |
| NOEXE     | Not Executable—The program section contains data only; it does not contain instructions.   |
| NOPIC     | Non-Position-Independent Content—The program section is assigned to a fixed location in virtual memory (when it is in a shareable image).  |
| NORD      | Nonreadable—Reserved for future use.   |
| NOSHR     | No Share—The program section is reserved for private use at execution time by the initiating process.  |
| NOWRT     | Nonwritable—The contents of the program section cannot be altered (written into) at execution time.  |
| OVR       | Overlay—Program sections with the same name and attributes, including OVR, have the same relocatable base address in memory. The allocated virtual address space is the requested allocation of the largest overlaying program section. Compare this attribute with its opposite, CON.   |
| PIC       | Position-Independent Content—The program section can be relocated; that is, it can be assigned to any memory area (when it is in a shareable image).   |
| RD        | Readable—Reserved for future use.  |
| REL       | Relocatable—The linker assigns the program section a relocatable base address. The contents of the program section can be code or data. Compare this attribute with its opposite, ABS.   |

(continued on next page)

**Table 6–6 (Cont.) Program Section Attributes**

| Attribute | Function  |
|-----------|---|
| SHR       | Share—The program section can be shared at execution time by multiple processes. This attribute is assigned to a program section that can be linked into a shareable image. |
| USR       | User Segment—Reserved for future use.   |
| VEC       | Vector-Containing—The program section contains a change mode vector indicating a privileged shareable image. You must use the SHR attribute with VEC.                       |
| WRT       | Write—The contents of the program section can be altered (written into) at execution time.  |

**Table 6–7 Default Program Section Attributes**

| Default Attribute | Opposite Attribute |
|-------------------|--------------------|
| CON               | OVR                |
| EXE               | NOEXE              |
| LCL               | GBL                |
| NOPIC             | PIC                |
| NOSHR             | SHR                |
| RD                | NORD               |
| REL               | ABS                |
| WRT               | NOWRT              |
| NOVEC             | VEC                |

## Description

.PSECT defines a program section and its attributes and refers to a program section once it is defined. Use program sections to do the following:

- Develop modular programs.
- Separate instructions from data.
- Allow different modules to access the same data.
- Protect read-only data and instructions from being modified.
- Identify sections of the object module to the debugger.
- Control the order in which program sections are stored in virtual memory.

The assembler automatically defines two program sections: the absolute program section and the unnamed (or blank) program section. Any symbol definitions that appear before any instruction, data, or .PSECT directive are placed in the absolute program section. Any instructions or data that appear before the first named program section is defined are placed in the unnamed program section. Any .PSECT directive that does not include a program section name specifies the unnamed program section.

A maximum of 254 user-defined, named program sections can be defined.

## Assembler Directives

### .PSECT

When the assembler encounters a .PSECT directive that specifies a new program section name, it creates a new program section and stores the name, attributes, and alignment of the program section. The assembler includes all data and instructions that follow the .PSECT directive in that program section until it encounters another .PSECT directive. The assembler starts all program sections at a location counter of 0, which is relocatable.

If the assembler encounters a .PSECT directive that specifies the name of a previously defined program section, it stores the new data or instructions after the last entry in the previously defined program section. The location counter is set to the value of the location counter at the end of the previously defined program section. You need not list the attributes when continuing a program section but any attributes that are listed must be the same as those previously in effect for the program section. A continuation of a program section cannot contain attributes conflicting with those specified in the original .PSECT directive.

The attributes listed in the .PSECT directive only describe the contents of the program section. The assembler does not check to ensure that the contents of the program section actually include the attributes listed. However, the assembler and the linker do check that all program sections with the same name have exactly the same attributes. The assembler and linker display an error message if the program section attributes are not consistent.

Program section names are independent of local symbol, global symbol, and macro names. You can use the same symbolic name for a program section and for a local symbol, global symbol, or macro name.

#### Notes

1. The .ALIGN directive cannot specify an alignment greater than that of the current program section; consequently, .PSECT should specify the largest alignment needed in the program section. For efficiency of execution, an alignment of longword or larger is recommended for all program sections that have longword data.
2. The attributes of the default absolute and the default unnamed program sections are listed in the following table. Note that the program section names include the periods (.) and enclosed spaces.

| Program SectionName | Attributes and Alignment                                    |
|---------------------|---|
| . ABS .             | NOPIC,USR,CON,ABS,LCL,NOSHR,NOEXE,<br>NORD,NOWRT,NOVEC,BYTE |
| . BLANK .           | NOPIC,USR,CON,REL,LCL,NOSHR,EXE,<br>RD,WRT,NOVEC,BYTE       |

#### Example

```
.PSECT CODE,NOWRT,EXE,LONG      ; Program section to contain
                                ; executable code
.PSECT RWDATA,WRT,NOEXE,QUAD    ; Program section to contain
                                ; modifiable data
```

## **.QUAD**

Quadword storage directive

### **Format**

```
.QUAD literal
.QUAD symbol
```

### **Parameters**

#### **literal**

Any constant value. This value can be preceded by ^O, ^B, ^X, or ^D to specify the radix as octal, binary, hexadecimal, or decimal, respectively; or it can be preceded by ^A to specify the ASCII text operator. Decimal is the default radix.

#### **symbol**

A symbol defined elsewhere in the program. This symbol results in a sign-extended, 32-bit value being stored in a quadword.

### **Description**

.QUAD generates 64 bits (8 bytes) of binary data.

#### **Note**

.QUAD is like .OCTA and different from other data storage directives (.BYTE, .WORD, and .LONG) in that it does not evaluate expressions and that it accepts only one value. It does not accept a list.

### **Example**

```
.QUAD ^A'..ASK?..'          ; Each ASCII character is stored
                             ;   in a byte
.QUAD 0                      ; QUAD 0
.QUAD ^X0123456789ABCDEF    ; QUAD hex value specified
.QUAD ^B1111000111001101    ; QUAD binary value specified
.QUAD LABEL                  ; LABEL has a 32-bit,
                             ;   zero-extended value.
```

## Assembler Directives

### .REFn

---

### .REFn

Operand generation directives

#### Format

.REF1 operand  
.REF2 operand  
.REF4 operand  
.REF8 operand  
.REF16 operand

#### Parameter

##### operand

An operand of byte, word, longword, quadword, or octaword context, respectively.

#### Description

VAX MACRO has the following five operand generation directives that you can use in macros to define new opcodes:

| Directive | Function                      |
|-----------|-------------------------------|
| .REF1     | Generates a byte operand      |
| .REF2     | Generates a word operand      |
| .REF4     | Generates a longword operand  |
| .REF8     | Generates a quadword operand  |
| .REF16    | Generates an octaword operand |

The .REFn directives are provided for compatibility with VAX MACRO Version 1.0. Because the .OPDEF directive provides greater functionality and is easier to use than .REFn, you should use .OPDEF instead of .REFn.

#### Example

```
.MACRO MOVL3 A,B,C
.BYTE ^XFF,^XA9
.REF4 A ; This operand has longword context
.REF4 B ; This operand has longword context
.REF4 C ; This operand has longword context
.ENDM MOVL3
MOVL3 R0,@LAB-1,(R7)+[R10]
```

This example uses .REF4 to create a new instruction, MOVL3, which uses the reserved opcode FF. See the example in .OPDEF for a preferred method to create a new instruction.

## **.REPEAT**

Repeat block directive

### **Format**

.REPEAT expression  
range  
.ENDR

### **Parameters**

#### **expression**

An expression whose value controls the number of times the range is to be assembled within the program. When the expression is less than or equal to zero, the repeat block is not assembled. The expression must be absolute and must not contain any undefined symbols (see Section 3.5).

#### **range**

The source text to be repeated the number of times specified by the value of the expression. The repeat block can contain macro definitions, indefinite repeat blocks, or other repeat blocks. .MEXIT is legal within the range.

### **Description**

.REPEAT repeats a block of code a specified number of times, in line with other source code. The .ENDR directive specifies the end of the range.

#### **Note**

The alternate form of .REPEAT is .REPT.

## Assembler Directives

### .REPEAT

#### Example

The macro definition is as follows:

```
.MACRO COPIES STRING,NUM
.REPEAT NUM
.ASCII /STRING/
.ENDR
.BYTE 0
.ENDM COPIES
```

The macro calls and expansions of the macro defined previously are as follows:

```
COPIES <ABCDEF>,5
.REPEAT 5
.ASCII /ABCDEF/
.ENDR
.ASCII /ABCDEF/
.ASCII /ABCDEF/
.ASCII /ABCDEF/
.ASCII /ABCDEF/
.ASCII /ABCDEF/
.BYTE 0

VARB = 3
COPIES <HOW MANY TIMES>,VARB
.REPEAT 3
.ASCII /HOW MANY TIMES/
.ENDR
.ASCII /HOW MANY TIMES/
.ASCII /HOW MANY TIMES/
.ASCII /HOW MANY TIMES/
.BYTE 0
```

---

## **.RESTORE\_PSECT**

Restore previous program section context directive

### **Format**

`.RESTORE_PSECT`

### **Description**

`.RESTORE_PSECT` retrieves the program section from the top of the program section context stack, an internal stack in the assembler. If the stack is empty when `.RESTORE_PSECT` is issued, the assembler displays an error message. When `.RESTORE_PSECT` retrieves a program section, it restores the current location counter to the value it had when the program section was saved. The local label block is also restored if it was saved when the program section was saved. See the description of `.SAVE_PSECT` for more information.

---

#### **Note**

---

The alternate form of `.RESTORE_PSECT` is `.RESTORE`.

---

### **Example**

`.RESTORE_PSECT` and `.SAVE_PSECT` are especially useful in macros that define program sections. The macro definition in the following example saves the current program section context and defines new program sections. Then, it restores the saved program section. If the macro did not save and restore the program section context each time the macro was invoked, the program section would change.

```

        .MACRO  INITD                                ; Initialize symbols
                                                ;   and data areas
        .SAVE_PSECT                                ; Save the current PSECT
        .PSECT  SYMBOLS,ABS                        ; Define new PSECT
HELP_LEV=2                                       ; Define symbol
MAXNUM=100                                       ; Define symbol
RATE1=16                                         ; Define symbol
RATE2=4                                           ; Define symbol
        .PSECT  DATA,NOEXE,LONG                 ; Define another PSECT
TABL:   .BLKL  100                                ; 100 longwords in TABL
TEMP:   .BLKB  16                                  ; More storage
        .RESTORE_PSECT                           ; Restore the PSECT
                                                ;   in effect when
                                                ;   MACRO is invoked
        .ENDM

```

## Assembler Directives

### .SAVE\_PSECT

---

## .SAVE\_PSECT

Save current program section context directive

### Format

```
.SAVE_PSECT [LOCAL_BLOCK]
```

### Parameter

#### LOCAL\_BLOCK

An optional keyword that specifies that the current local label is to be saved with the program section context.

### Description

.SAVE\_PSECT stores the current program section context on the top of the program section context stack, an internal assembler stack. It leaves the current program section context in effect. The program section context stack can hold 31 entries. Each entry includes the value of the current location counter and the maximum value assigned to the location counter in the current program section. If the stack is full when .SAVE\_PSECT is encountered, an error occurs.

.SAVE\_PSECT and .RESTORE\_PSECT are especially useful in macros that define program sections. See the description of .RESTORE\_PSECT for another example using .SAVE\_PSECT.

#### Note

The alternate form of .SAVE\_PSECT is .SAVE.

### Example

The macro definition is as follows:

```
.MACRO ERR_MESSAGE,TEXT           ; Set up lists of messages
                                   ; and pointers
                                   ;
.IIF NOT_DEFINED MESSAGE_INDEX, MESSAGE_INDEX=0
.SAVE_PSECT -
    LOCAL_BLOCK                   ; Keep local labels
.PSECT MESSAGE_TEXT               ; List of error messages
MESSAGE::
    .ASCIC /TEXT/
    .PSECT MESSAGE_POINTERS       ; Addresses of error
    .ADDRESS -                    ; messages
    MESSAGE                       ; Store one pointer
    .RESTORE_PSECT                ; Get back local labels
    PUSHL #MESSAGE_INDEX          ;
    CALLS #1,PRINT_MESS           ; Print message
MESSAGE_INDEX=MESSAGE_INDEX+1
.ENDM ERR_MESSAGE
```

Macro call:

```
RESETS: CLRL    R4
        BLBC    R0,30$
        ERR_MESSAGE    <STRING TOO SHORT> ; Add "STRING TOO SHORT"
                                ; to list of error
30$:    RSB                                ; messages
```

By using `.SAVE_PSECT LOCAL_BLOCK`, the local label `30$` is defined in the same local label block as the reference to `30$`. If a local label is not defined in the block in which it is referenced, the assembler produces the following error message:

```
%MACRO-E-UNDEFSYM, Undefined Symbol
```

## Assembler Directives

### .SHOW .NOSHOW

---

## .SHOW .NOSHOW

### 4515CH6\_630

Listing directives

#### Format

.SHOW [argument-list]

.NOSHOW [argument-list]

#### Parameter

##### argument-list

One or more of the optional symbolic arguments defined in Table 6–8. You can use either the long form or the short form of the arguments. You can use each argument alone or in combination with other arguments. If you specify multiple arguments, you must separate them by commas (,), tabs, or spaces. If any argument is not specifically included in a listing control statement, the assembler assumes its default value (SHOW or NOSHOW) throughout the source program.

**Table 6–8 .SHOW and .NOSHOW Symbolic Arguments**

| Long Form    | Short Form | Default | Function   |
|--------------|------------|---------|--|
| BINARY       | MEB        | NOSHOW  | Lists macro and repeat block expansions that generate binary code. BINARY is a subset of EXPANSIONS. |
| CALLS        | MC         | SHOW    | Lists macro calls and repeat block specifiers.   |
| CONDITIONALS | CND        | SHOW    | Lists unsatisfied conditional code associated with the conditional assembly directives.              |
| DEFINITIONS  | MD         | SHOW    | Lists macro and repeat range definitions that appear in an input source file.                        |
| EXPANSIONS   | ME         | NOSHOW  | Lists macro and repeat range expansions.   |

#### Description

.SHOW and .NOSHOW specify listing control options in the source text of a program. You can use .SHOW and .NOSHOW with or without an argument list.

When you use them with an argument list, .SHOW includes and .NOSHOW excludes the lines specified in Table 6–8. .SHOW and .NOSHOW control the listing of the source lines that are in conditional assembly blocks (see the description of .IF), macros, and repeat blocks.

When you use them without arguments, these directives alter the listing level count. The listing level count is initialized to 0. Each time `.SHOW` appears in a program, the listing level count is incremented; each time `.NOSHOW` appears in a program, the listing level count is decremented.

When the listing level count is negative, the listing is suppressed (unless the line contains an error). Conversely, when the listing level count is positive, the listing is generated. When the count is 0, the line is either listed or suppressed, depending on the value of the listing control symbolic arguments.

**Notes**

1. The listing level count allows macros to be listed selectively; a macro definition can specify `.NOSHOW` at the beginning to decrement the listing count and can specify `.SHOW` at the end to restore the listing count to its original value.
2. The alternate forms of `.SHOW` and `.NOSHOW` are `.LIST` and `.NLIST`.

**Example**

```
.MACRO XX
.
.
.
.SHOW                ; List next line
X=.
.NOSHOW              ; Do not list remainder
.                    ;   of macro expansion
.
.
.ENDM
.NOSHOW EXPANSIONS  ; Do not list macro
.                    ;   expansions
XX
X=.
```

## Assembler Directives

### .SIGNED\_BYTE

---

### .SIGNED\_BYTE

Signed byte data directive

#### Format

```
.SIGNED_BYTE expression-list
```

#### Parameters

##### **expression-list**

An expression or list of expressions separated by commas (.). You have the option of following each expression with a repetition factor delimited by square brackets ([]).

An expression followed by a repetition factor has the format:

```
expression1[expression2]
```

##### **expression1**

An expression that specifies the value to be stored. The value must be in the range -128 to +127.

##### **[expression2]**

An expression that specifies the number of times the value will be repeated. The expression must not contain any undefined symbols and must be an absolute expression (see Section 3.5). The square brackets are required.

#### Description

.SIGNED\_BYTE is equivalent to .BYTE, except that VAX MACRO indicates that the data is signed in the object module. The linker uses this information to test for overflow conditions.

##### **Note**

Specifying .SIGNED\_BYTE allows the linker to detect overflow conditions when the value of the expression is in the range of 128 to 255. Values in this range can be stored as unsigned data but cannot be stored as signed data in a byte.

#### Example

```
.SIGNED_BYTE LABEL1-LABEL2 ; Data must fit  
.SIGNED_BYTE ALPHA[20] ; in byte
```

---

## **.SIGNED\_WORD**

Signed word storage directive

### **Format**

`.SIGNED_WORD` expression-list

### **Parameters**

#### **expression-list**

An expression or list of expressions separated by commas (.). You have the option of following each expression with a repetition factor delimited by square brackets ([]).

An expression followed by a repetition factor has the format:

expression1[expression2]

#### **expression1**

An expression that specifies the value to be stored. The value must be in the range -32,768 to +32,767.

#### **[expression2]**

An expression that specifies the number of times the value will be repeated. The expression must not contain any undefined symbols and must be an absolute expression (see Section 3.5). The square brackets ([ ]) are required.

### **Description**

`.SIGNED_WORD` is equivalent to `.WORD` except that the assembler indicates that the data is signed in the object module. The linker uses this information to test for overflow conditions. `.SIGNED_WORD` is useful after the case instruction to ensure that the displacement fits in a word.

#### **Note**

Specifying `.SIGNED_WORD` allows the linker to detect overflow conditions when the value of the expression is in the range of 32,768 to 65,535. Values in this range can be stored as unsigned data but cannot be stored as signed data in a word.

## Assembler Directives

### .SIGNED\_WORD

#### Example

```
.MACRO CASE,SRC,DISPLIST,TYPE=W,LIMIT=#0,NMODE=S^#/?BASE,?MAX
; MACRO to use CASE instruction,
; SRC is selector, DISPLIST
; is list of displacements, TYPE
; is B (byte) W (word) L (long),
; LIMIT is base value of selector
CASE'TYPE SRC,LIMIT,NMODE'<<MAX-BASE>/2>-1
; Case instruction
BASE: ; Local label specifying base
.IRP EP,<DISPLIST> ; to set up offset list
.SIGNED_WORD EP-BASE ; Offset list
.ENDR ;
MAX: ; Local label used to count
.ENDM CASE ; args
CASE IVAR <ERR_PROC,SORT,REV_SORT> ; If IVAR=0, error
CASEW IVAR,#0,S^#<<30001$-30000$>/2>-1
30000$: ; Local label specifying base
.SIGNED_WORD ERR_PROC-30000$ ; Offset list
.SIGNED_WORD SORT-30000$ ; Offset list
.SIGNED_WORD REV_SORT-30000$ ; Offset list
30001$: ; Local label used to count args
; =1, forward sort; =2, backward
; sort
CASE TEST <TEST1,TEST2,TEST3>,L,#1
CASEL TEST,#1,S^#<<30003$-30002$>/2>-1
30002$: ; Local label specifying base
.SIGNED_WORD TEST1-30002$ ; Offset list
.SIGNED_WORD TEST2-30002$ ; Offset list
.SIGNED_WORD TEST3-30002$ ; Offset list
30003$: ; Local label used to count args
; Value of TEST can be 1, 2, or 3
```

In this example, the CASE macro uses .SIGNED\_WORD to create a CASEB, CASEW, or CASEL instruction.

---

## .SUBTITLE

Subtitle directive

### Format

.SUBTITLE comment-string

### Parameter

#### **comment-string**

An ASCII string from 1 to 40 characters long; excess characters are truncated.

### Description

.SUBTITLE causes the assembler to print the line of text, represented by the comment-string, in the table of contents (which the assembler produces immediately before the assembly listing). The assembler also prints the line of text as the subtitle on the second line of each assembly listing page. This subtitle text is printed on each page until altered by a subsequent .SUBTITLE directive in the program.

#### **Note**

The alternate form of .SUBTITLE is .SBTTL.

### Examples

1. .SUBTITLE CONDITIONAL ASSEMBLY

This directive causes the assembler to print the following text as the subtitle of the assembly listing:

```
CONDITIONAL ASSEMBLY
```

It also causes the text to be printed out in the listing's table of contents, along with the source page number and the line sequence number of the source statement where .SUBTITLE was specified. The table of contents would have the following format:

2. TABLE OF CONTENTS

```
(1)    5000 ASSEMBLER DIRECTIVES
(2)    300  MACRO DEFINITIONS
(2)    2300 DATA TABLES AND INITIALIZATION
(3)    4800 MAIN ROUTINES
(4)    2800 CALCULATIONS
(4)    5000 I/O ROUTINES
(5)    1300 CONDITIONAL ASSEMBLY
```

## Assembler Directives

### .TITLE

---

### .TITLE

Title directive

#### Format

```
.TITLE  module-name comment-string
```

#### Parameters

**module-name**

An identifier from 1 to 31 characters long.

**comment-string**

An ASCII string from 1 to 40 characters long; excess characters are truncated.

#### Description

.TITLE assigns a name to the object module. This name is the first 31 or fewer nonblank characters following the directive.

#### Notes

1. The module name specified with .TITLE bears no relationship to the file specification of the object module, as specified in the VAX MACRO command line. The object module name appears in the linker load map and is also the module name that the debugger and librarian recognize.
2. If .TITLE is not specified, VAX MACRO assigns the default name .MAIN to the object module. If more than one .TITLE directive is specified in the source program, the last .TITLE directive encountered establishes the name for the entire object module.
3. When evaluating the module name, VAX MACRO ignores all spaces, tabs, or both, up to the first nonspace/nontab character after .TITLE.

#### Example

```
.TITLE  EVAL    Evaluates Expressions
```

---

## .TRANSFER

Transfer directive

### Format

.TRANSFER symbol

### Parameter

#### symbol

A global symbol that is an entry point in a procedure or routine.

### Description

.TRANSFER redefines a global symbol for use in a shareable image. The linker redefines the symbol as the value of the location counter at the .TRANSFER directive after a shareable image is linked.

To make program maintenance easier, programs should not need to be relinked when the shareable images to which they are linked change. To avoid relinking entire programs when their linked shareable images change, keep the entry points in the changed shareable image at their original addresses. To do this, create an object module that contains a transfer vector for each entry point. Do not change the order of the transfer vectors. Link this object module at the beginning of the shareable image. The addresses of the entry points remain fixed even if the source code for a routine is changed. After each .TRANSFER directive, create a register save mask (for procedures only) and a branch to the first instruction of the routine.

The .TRANSFER directive does not cause any memory to be allocated and does not generate any binary code. It merely generates instructions to the linker to redefine the symbol when a shareable image is being created.

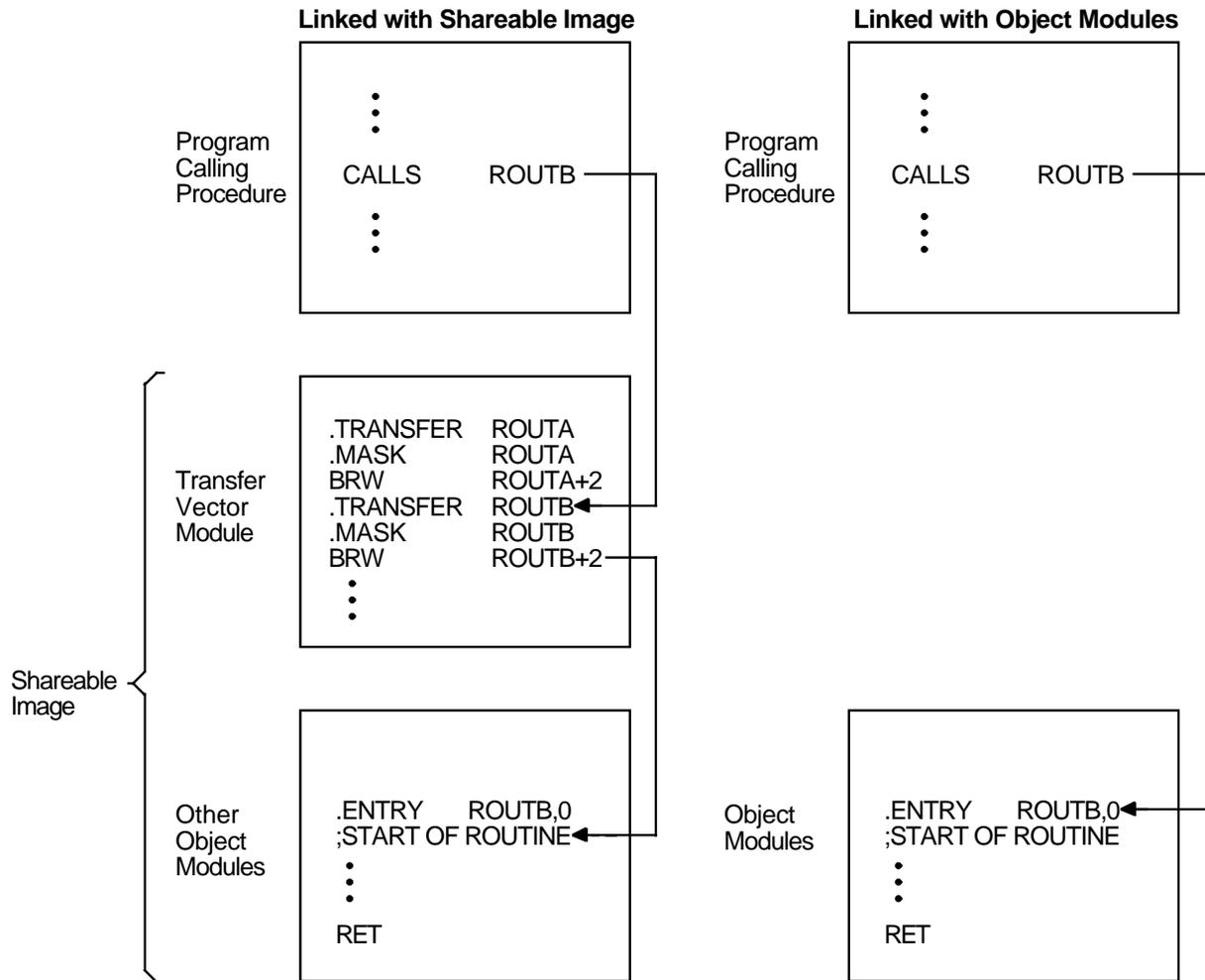
Use .TRANSFER with procedures entered by the CALLS or CALLG instruction. In this case, use .TRANSFER with the .ENTRY and .MASK directives. The branch to the actual routine must be a branch to the entry point plus 2 to bypass the 2-byte register save mask.

Figure 6-1 illustrates the use of transfer vectors.

# Assembler Directives

## .TRANSFER

Figure 6-1 Using Transfer Vectors



ZK-0535-GE

## Example

```
.TRANSFER ROUTINE_A
.MASK      ROUTINE_A, ^M<R4,R5> ; Copy entry mask
                                     ; and add registers
                                     ; R4 and R5
BRW        ROUTINE_A+2          ; Branch to routine
                                     ; (past entry mask)
.
.
.ENTRY     ROUTINE_A, ^M<R2,R3> ; ENTRY point, save
                                     ; registers R2 and R3
.
.
RET
```

In this example, `.MASK` copies the entry mask of a routine to the new entry address specified by `.TRANSFER`. If the routine is placed in a shareable image and then called, registers R2, R3, R4, and R5 will be saved.

## Assembler Directives

### .WARN

---

### .WARN

Warning directive

#### Format

```
.WARN [expression] ;comment
```

#### Parameters

##### **expression**

An expression whose value is displayed when .WARN is encountered during assembly.

##### **;comment**

A comment that is displayed when .WARN is encountered during assembly. The comment must be preceded by a semicolon (;).

#### Description

.WARN causes the assembler to display a warning message on the terminal or in the batch log file, and in the listing file (if there is one).

#### Notes

1. .WARN, .ERROR, and .PRINT are called the message display directives. Use them to display information indicating that a macro call contains an error or an illegal set of conditions.
2. When the assembly is finished, the assembler displays on the terminal or in the batch log file, the total number of errors, warnings, and information messages, and the page numbers and line numbers of the lines causing the errors or warnings.
3. If .WARN is included in a macro library, end the comment with an additional semicolon. If you omit the semicolon, the comment will be stripped from the directive and will not be displayed when the macro is called.
4. The line containing the .WARN directive is not included in the listing file.
5. If the expression has a value of zero, it is not displayed in the warning message.

## Example

```
.IF DEFINED FULL
.IF DEFINED DOUBLE_PREC
.WARN      ; This combination not tested
.ENDC
.ENDC
```

If the symbols **FULL** and **DOUBLE\_PREC** are both defined, the following warning message is displayed:

```
%MACRO-W-GENWRN, Generated WARNING: This combination not tested
```

## Assembler Directives

### .WEAK

---

### .WEAK

Weak symbol attribute directive

#### Format

```
.WEAK symbol-list
```

#### Parameter

**symbol-list**

A list of legal symbols separated by commas (,).

#### Description

.WEAK specifies symbols that are either defined externally in another module or defined globally in the current module. .WEAK suppresses any object library search for the symbol.

When .WEAK specifies a symbol that is not defined in the current module, the symbol is externally defined. If the linker finds the symbol's definition in another module, it uses that definition. If the linker does not find an external definition, the symbol has a value of zero and the linker does not report an error. The linker does not search a library for the symbol, but if a module brought in from a library for another reason contains the symbol definition, the linker uses it.

When .WEAK specifies a symbol that is defined in the current module, the symbol is considered to be globally defined. However, if this module is inserted in an object library, this symbol is not inserted in the library's symbol table. Consequently, searching the library at link time to resolve this symbol does not cause the module to be included.

#### Example

```
.WEAK IOCAR,LAB_3
```

## .WORD

Word storage directive

### Format

.WORD expression-list

### Parameters

#### expression-list

One or more expressions separated by commas (,). You have the option of following each expression by a repetition factor delimited with square brackets ([]).

An expression followed by a repetition factor has the format:

expression1[expression2]

#### expression1

An expression that specifies the value to be stored.

#### [expression2]

An expression that specifies the number of times the value will be repeated. The expression must not contain any undefined symbols and must be an absolute expression (see Section 3.5). The square brackets are required.

### Description

.WORD generates successive words (2 bytes) of data in the object module.

#### Notes

1. The expression is first evaluated as a longword, then truncated to a word. The value of the expression should be in the range of -32,768 to +32,767 for signed data or 0 to 65,535 for unsigned data. The assembler displays an error if the high-order 2 bytes of the longword expression have a value other than zero or ^XFFFF.
2. The .SIGNED\_WORD directive is the same as .WORD except that the assembler displays a diagnostic message if a value is in the range from 32,768 to 65,535.

### Example

```
.WORD    ^X3F,FIVE[3],32
```



---

# VAX Data Types and Instruction Set

Part II describes the VAX data types, addressing mode formats, instruction formats, and the instructions themselves.



---

## Terminology and Conventions

The following sections describe terminology and conventions used in Part II of this volume.

### 7.1 Numbering

All numbers, unless otherwise indicated, are decimal. Where there is ambiguity, numbers other than decimal are indicated with the base in English following the number in parentheses. For example:

FF (hex)

### 7.2 UNPREDICTABLE and UNDEFINED

Results specified as UNPREDICTABLE may vary from moment to moment, implementation to implementation, and instruction to instruction within implementations. Software can never depend on results specified as UNPREDICTABLE. Operations specified as UNDEFINED may vary from moment to moment, implementation to implementation, and instruction to instruction within implementations. The operation might vary from causing no effect to stopping system operation. UNDEFINED operations must not cause the processor to hang—to reach an unhalted state from which there is no transition to a normal state in which the machine executes instructions. Note the distinction between result and operation. Nonprivileged software cannot invoke UNDEFINED operations. When the operation of the VAX scalar processor becomes UNDEFINED, so does the operation of its associated processor. The converse is not true; when the operation of the vector processor becomes UNDEFINED, the operation of the scalar processor need not become UNDEFINED.

### 7.3 Ranges and Extents

Ranges are specified in English and are inclusive (for example, a range of integers 0 to 4 includes the integers 0, 1, 2, 3, and 4). Extents are specified by a pair of numbers separated by a colon and are inclusive (that is, bits 7:3 specifies an extent of bits including bits 7, 6, 5, 4, and 3).

### 7.4 MBZ

Fields specified as MBZ (must be zero) must never be filled by software with a nonzero value. If the processor encounters a nonzero value in a field specified as MBZ, a reserved operand fault or abort occurs if that field is accessible to nonprivileged software. MBZ fields that are accessible only to privileged software (kernel mode) cannot be checked for nonzero value by some or all VAX implementations. Nonzero values in MBZ fields accessible only to privileged software may produce UNDEFINED operation.

## Terminology and Conventions

### 7.5 RAZ

### 7.5 RAZ

Fields specified as RAZ (read as zero) return a zero when read.

### 7.6 SBZ

Fields specified as SBZ (should be zero) should be filled by software with a zero value. Non-zero values in SBZ fields produce UNPREDICTABLE results and may produce extraneous instruction-issue delays.

### 7.7 Reserved

Unassigned values of fields are reserved for future use. In many cases, some values are indicated as reserved to CSS and customers. Only these values should be used for nonstandard applications. The values indicated as reserved to Compaq and all MBZ (must be zero) fields are to be used only to extend future standard architecture.

### 7.8 Figure Drawing Conventions

Figures that depict registers or memory follow the convention that increasing addresses extend from right to left and from top to bottom.

---

## Basic Architecture

The following sections describe the basic VAX architecture, including the following:

- Address space
- Data types
- Processor status longword (PSL)
- Permanent exception enables
- Instruction and addressing mode formats

### 8.1 Basic Architecture

The VAX architecture represents a significant extension of the PDP-11 family architecture. It shares byte addressing with the PDP-11 family, similar I/O and interrupt structures, and identical data formats. Although the instruction set is not strictly compatible with the PDP-11 system, it is related and can be mastered easily by a PDP-11 programmer. Likewise, the similarity allows straightforward manual conversion of existing PDP-11 programs to the VAX system. Existing user-mode PDP-11 programs that do not need the extended features of a VAX system can run unchanged in the PDP-11 compatibility mode provided in the VAX architecture.

As compared to the PDP-11 architecture, VAX architecture offers a greatly extended virtual address space, additional instructions and data types, and new addressing modes. VAX architecture also provides a sophisticated memory management and protection mechanism, and hardware-assisted process sharing and synchronization.

A number of specific goals are achieved in the VAX design. For example:

- VAX architecture has maximal compatibility with the PDP-11 architecture consistent with a significant extension of the virtual address space and a significant functional enhancement.
- High bit efficiency is achieved by a wide range of data types and new addressing modes.
- The systematic, elegant instruction set with orthogonality of operators, data types, and addressing modes can be exploited easily, particularly by high-level language processors.
- The VAX system is extensible. The instruction set is designed so that new data types and operators can be included efficiently in a manner consistent with the currently defined operators and data types.
- The architecture is suited, in terms of price and performance, to a wide range of computer system implementations sold by Compaq Computer Corporation.

## Basic Architecture

### 8.1 Basic Architecture

With the addition of vector processing, VAX architecture can be classified into the following two parts:

- A vector part, which includes the instructions, registers, and execution model for vector processing.
- A scalar part, which includes the remainder of the architecture.

Where confusion may be possible, this manual uses the term **scalar** to describe objects belonging to the scalar part of the architecture — as in scalar instructions and scalar processor. Similarly, the term **vector** is used to describe parts belonging to the vector part of the architecture — as in vector registers, and vector instructions. With the exception of Chapter 10, instructions, exceptions, registers, and other objects described in the rest of the this manual refer to the scalar part of the architecture unless otherwise stated.

## 8.2 VAX Addressing

The basic addressable unit in VAX MACRO is the 8-bit byte. Virtual addresses are 32 bits long. Therefore, the virtual address space is  $2^{32}$  (approximately 4.3 billion) bytes. Virtual addresses as seen by the program are translated into physical memory addresses by the memory management mechanism.

## 8.3 Data Types

The following sections describe the VAX data types.

### 8.3.1 Byte

A byte is 8 contiguous bits starting on an addressable byte boundary. The bits are numbered from right to left 0 to 7.

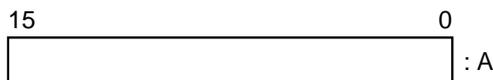


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A byte is specified by its address A. When interpreted arithmetically, a byte is a two's complement integer with bits of increasing significance ranging from bit 0 to bit 6, with bit 7 the sign bit. The value of the integer is in the range -128 to +127. For the purposes of addition, subtraction, and comparison, VAX instructions also provide direct support for the interpretation of a byte as an unsigned integer with bits of increasing significance ranging from bit 0 to bit 7. The value of the unsigned integer is in the range 0 to 255.

### 8.3.2 Word

A word is 2 contiguous bytes starting on an arbitrary byte boundary. The 16 bits are numbered from right to left 0 to 15.



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A word is specified by its address, A, which is the address of the byte containing bit 0. When interpreted arithmetically, a word is a two's complement integer with bits of increasing significance ranging from bit 0 to bit 14, with bit 15 the

sign bit. The value of the integer is in the range -32,768 to +32,767. For the purposes of addition, subtraction, and comparison, VAX instructions also provide direct support for the interpretation of a word as an unsigned integer with bits of increasing significance ranging from bit 0 to bit 15. The value of the unsigned integer is in the range 0 to 65,535.

### 8.3.3 Longword

A longword is 4 contiguous bytes starting on an arbitrary byte boundary. The 32 bits are numbered from right to left 0 to 31.

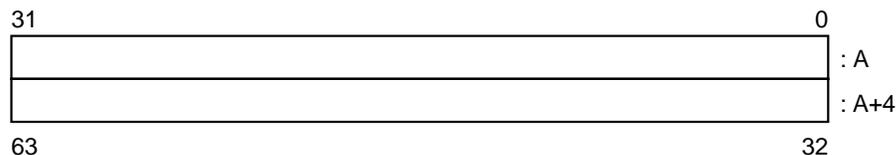


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A longword is specified by its address, A, which is the address of the byte containing bit 0. When interpreted arithmetically, a longword is a two's complement integer with bits of increasing significance ranging from bit 0 to bit 30, with bit 31 the sign bit. The value of the integer is in the range -2,147,483,648 to +2,147,483,647. For the purposes of addition, subtraction, and comparison, VAX instructions also provide direct support for the interpretation of a longword as an unsigned integer with bits of increasing significance ranging from bit 0 to bit 31. The value of the unsigned integer is in the range 0 to 4,294,967,295.

### 8.3.4 Quadword

A quadword is 8 contiguous bytes starting on an arbitrary byte boundary. The 64 bits are numbered from right to left 0 to 63.



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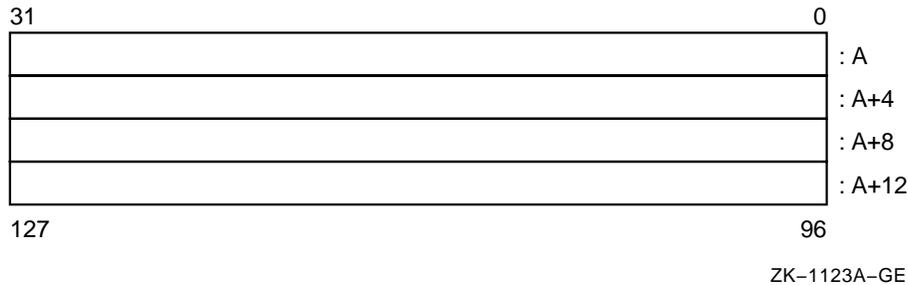
A quadword is specified by its address, A, which is the address of the byte containing bit 0. When interpreted arithmetically, a quadword is a two's complement integer with bits of increasing significance ranging from bit 0 to bit 62, with bit 63 the sign bit. The value of the integer is in the range  $-2^{63}$  to  $+2^{63}-1$ . The quadword data type is not fully supported by VAX instructions.

### 8.3.5 Octaword

An octaword is 16 contiguous bytes starting on an arbitrary byte boundary. The 128 bits are numbered from right to left 0 to 127.

## Basic Architecture

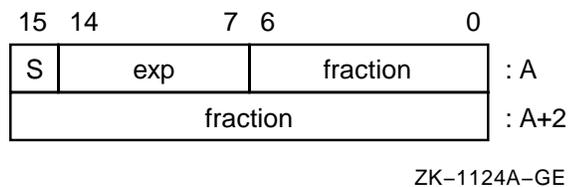
### 8.3 Data Types



An octaword is specified by its address, A, which is the address of the byte containing bit 0. When interpreted arithmetically, an octaword is a two's complement integer with bits of increasing significance ranging from bit 0 to bit 126, with bit 127 the sign bit. The value of the integer is in the range  $-2^{127}$  to  $+2^{127}-1$ . The octaword data type is not fully supported by VAX instructions.

#### 8.3.6 F\_floating

An F\_floating datum is 4 contiguous bytes starting on an arbitrary byte boundary. The 32 bits are labeled from right to left 0 to 31.



An F\_floating datum is specified by its address, A, which is the address of the byte containing bit 0. The form of an F\_floating datum is sign magnitude with bit 15 as the sign bit, bits 14:7 as an excess 128 binary exponent, and bits 6:0 and 31:16 as a normalized 24-bit fraction with the redundant most-significant fraction bit not represented. Within the fraction, bits of increasing significance range from bits 16 to 31 and 0 to 6. The 8-bit exponent field encodes the values 0 to 255. An exponent value of zero, together with a sign bit of zero, is taken to indicate that the F\_floating datum has a value of zero. Exponent values of 1 to 255 indicate true binary exponents of  $-127$  to  $+127$ . An exponent value of zero, together with a sign bit of 1, is taken as reserved. Floating-point instructions processing a reserved operand take a reserved operand fault (see Appendix E). The value of an F\_floating datum is in the approximate range  $.29 \times 10^{-38}$  to  $1.7 \times 10^{38}$ . The precision of an F\_floating datum is approximately one part in  $2^{23}$ ; that is, typically 7 decimal digits.

#### 8.3.7 D\_floating

A D\_floating datum is 8 contiguous bytes starting on an arbitrary byte boundary. The bits are labeled from right to left 0 to 63.

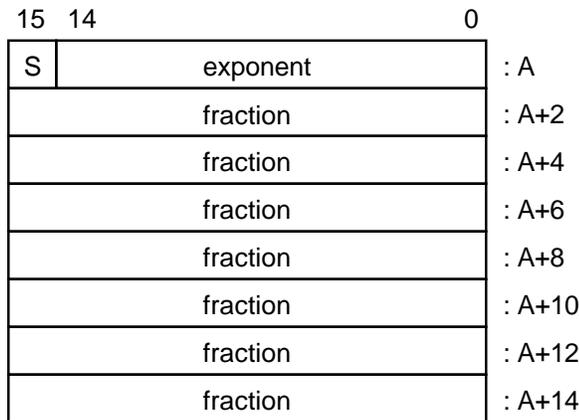


## Basic Architecture

### 8.3 Data Types

#### 8.3.9 H\_floating

An H\_floating datum is 16 contiguous bytes starting on an arbitrary byte boundary. The 128 bits are labeled from right to left 0 to 127.



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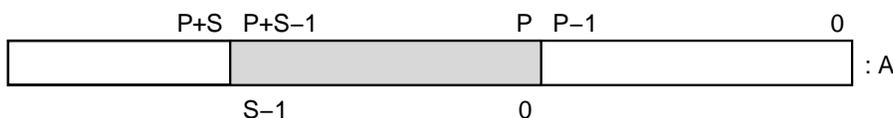
An H\_floating datum is specified by its address, A, which is the address of the byte containing bit 0. The form of an H\_floating datum is sign magnitude with bit 15 as the sign bit, bits 14:0 as an excess 16,384 binary exponent, and bits 127:16 as a normalized 113-bit fraction with the redundant most-significant fraction bit not represented. Within the fraction, bits of increasing significance range from bits 112 to 127, 96 to 111, 80 to 95, 64 to 79, 48 to 63, 32 to 47, and 16 to 31. The 15-bit exponent field encodes the values 0 to 32,767. An exponent value of zero, together with a sign bit of 0, is taken to indicate that the H\_floating datum has a value of zero. Exponent values of 1 to 32,767 indicate true binary exponents of -16,383 to +16,383. An exponent value of zero, together with a sign bit of 1, is taken as reserved. Floating-point instructions processing a reserved operand take a reserved operand fault (see Appendix E). The value of an H\_floating datum is in the approximate range  $.84 \cdot 10^{-4932}$  to  $.59 \cdot 10^{4932}$ . The precision of an H\_floating datum is approximately one part in  $2^{112}$ , typically, 33 decimal digits.

#### 8.3.10 Variable-Length Bit Field

A variable-length bit field is 0 to 32 contiguous bits located arbitrarily with respect to byte boundaries. A variable-length bit field is specified by three attributes:

- Address A of a byte
- Bit position P, which is the starting location of the field with respect to bit 0 of the byte at A
- Size S of the field

The specification of a bit field is indicated by the following figure, where the field is the shaded area.



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For bit strings in memory, the position is in the range  $-2^{31}$  to  $2^{31}-1$  and is conveniently viewed as a signed 29-bit byte offset and a 3-bit, bit-within-byte field.

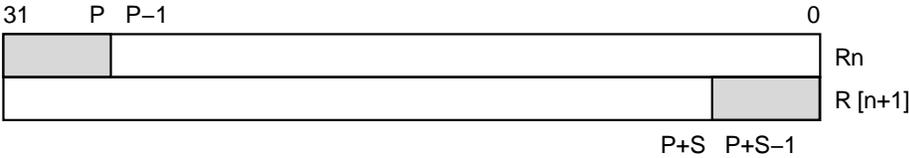


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The sign-extended, 29-bit byte offset is added to the address *A*; the resulting address specifies the byte in which the field begins. The 3-bit, bit-within-byte field encodes the starting position (0 to 7) of the field within that byte. The VAX field instructions provide direct support for the interpretation of a field as a signed or unsigned integer. When interpreted as a signed integer, it is two's complement with bits of increasing significance ranging from bits 0 to *S*-2; bit *S*-1 is the sign bit. When interpreted as an unsigned integer, bits of increasing significance range from bits 0 to *S*-1. A field of size zero has a value identically equal to zero.

A variable-length bit field may be contained in 1 to 5 bytes. From a memory management point of view, only the minimum number of aligned longwords necessary to contain the field may be actually referenced.

For bit fields in registers, the position is in the range 0 to 31. The position operand specifies the starting position (0 to 31) of the field in the register. A variable-length bit field may be contained in two registers if the sum of position and size exceeds 32.



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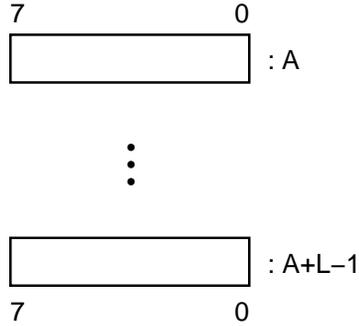
For further details on the specification of variable-length bit fields, see the descriptions of the variable-length bit field instructions in Section 9.2.3.

**8.3.11 Character String**

A character string is a contiguous sequence of bytes in memory. A character string is specified by two attributes: the address *A* of the first byte of the string, and the length *L* of the string in bytes. Thus, the format of a character string is represented as follows:

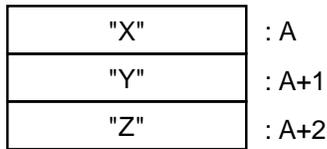
## Basic Architecture

### 8.3 Data Types



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The address of a string specifies the first character of a string. Thus “XYZ” is represented as follows:



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The length L of a string is in the range 0 to 65,535.

#### 8.3.12 Trailing Numeric String

A trailing numeric string is a contiguous sequence of bytes in memory. The string is specified by two attributes: the address A of the first byte (most-significant digit) of the string, and the length L of the string in bytes.

All bytes of a trailing numeric string, except the least-significant digit byte, must contain an ASCII decimal digit character (0 to 9).

The representation for the high-order digits is as follows:

| Digit | Decimal | Hex | ASCII Character |
|-------|---------|-----|-----------------|
| 0     | 48      | 30  | 0               |
| 1     | 49      | 31  | 1               |
| 2     | 50      | 32  | 2               |
| 3     | 51      | 33  | 3               |
| 4     | 52      | 34  | 4               |
| 5     | 53      | 35  | 5               |
| 6     | 54      | 36  | 6               |
| 7     | 55      | 37  | 7               |
| 8     | 56      | 38  | 8               |
| 9     | 57      | 39  | 9               |

The highest-addressed byte of a trailing numeric string represents an encoding of both the least-significant digit and the sign of the numeric string. The VAX

numeric string instructions support any encoding; however, Compaq software uses three encodings. These are as follows:

- Unsigned numeric encoding, in which there is no sign and the least-significant digit contains an ASCII decimal digit character
- Zoned numeric encoding
- Overpunched numeric encoding

Because compilers of many manufacturers over the years have used the overpunch format and various card encodings, several variations in overpunch format have evolved. Typically, these alternate forms are accepted on input; the normal form is generated as the output for all operations. The valid representations of the digit and sign in each of the latter two formats is indicated in Table 8–1 and Table 8–2.

**Table 8–1 Representation of Least-Significant Digit and Sign in Zoned Numeric Format**

| Digit | Decimal | Hex | ASCII Character |
|-------|---------|-----|-----------------|
| 0     | 48      | 30  | 0               |
| 1     | 49      | 31  | 1               |
| 2     | 50      | 32  | 2               |
| 3     | 51      | 33  | 3               |
| 4     | 52      | 34  | 4               |
| 5     | 53      | 35  | 5               |
| 6     | 54      | 36  | 6               |
| 7     | 55      | 37  | 7               |
| 8     | 56      | 38  | 8               |
| 9     | 57      | 39  | 9               |
| -0    | 112     | 70  | p               |
| -1    | 113     | 71  | q               |
| -2    | 114     | 72  | r               |
| -3    | 115     | 73  | s               |
| -4    | 116     | 74  | t               |
| -5    | 117     | 75  | u               |
| -6    | 118     | 76  | v               |
| -7    | 119     | 77  | w               |
| -8    | 120     | 78  | x               |
| -9    | 121     | 79  | y               |

## Basic Architecture

### 8.3 Data Types

**Table 8–2 Representation of Least-Significant Digit and Sign in Overpunch Format**

| Digit | Decimal | Hex | ASCII Character |      |
|-------|---------|-----|-----------------|------|
|       |         |     | Norm            | Alt. |
| 0     | 123     | 7B  | {               | 0[?  |
| 1     | 65      | 41  | A               | 1    |
| 2     | 66      | 42  | B               | 2    |
| 3     | 67      | 43  | C               | 3    |
| 4     | 68      | 44  | D               | 4    |
| 5     | 69      | 45  | E               | 5    |
| 6     | 70      | 46  | F               | 6    |
| 7     | 71      | 47  | G               | 7    |
| 8     | 72      | 48  | H               | 8    |
| 9     | 73      | 49  | I               | 9    |
| -0    | 125     | 7D  | }               | ]!   |
| -1    | 74      | 4A  | J               |      |
| -2    | 75      | 4B  | K               |      |
| -3    | 76      | 4C  | L               |      |
| -4    | 77      | 4D  | M               |      |
| -5    | 78      | 4E  | N               |      |
| -6    | 79      | 4F  | O               |      |
| -7    | 80      | 50  | P               |      |
| -8    | 81      | 51  | Q               |      |
| -9    | 82      | 52  | R               |      |

The length L of a trailing numeric string must be in the range 0 to 31 (0 to 31 digits). The value of a zero-length string is zero.

The address A of the string specifies the byte of the string containing the most-significant digit. Digits of decreasing significance are assigned to increasing addresses. Thus “123” is represented as follows:

Zoned Format or Unsigned

|   |   |   |   |       |
|---|---|---|---|-------|
| 7 | 4 | 3 | 0 |       |
| 3 |   | 1 |   | : A   |
| 3 |   | 2 |   | : A+1 |
| 3 |   | 3 |   | : A+2 |

Overpunch Format

|   |   |   |   |       |
|---|---|---|---|-------|
| 7 | 4 | 3 | 0 |       |
| 3 |   | 1 |   | : A   |
| 3 |   | 2 |   | : A+1 |
| 4 |   | 3 |   | : A+2 |

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The trailing numeric string with a value of “-123” is represented as follows:

| Zoned Format |   |   |   | Overpunch Format |   |   |   |
|--------------|---|---|---|------------------|---|---|---|
| 7            | 4 | 3 | 0 | 7                | 4 | 3 | 0 |
| 3            | 3 | 1 | 0 | 3                | 3 | 1 | 0 |
| : A          |   |   |   | : A              |   |   |   |
| 3            | 3 | 2 | 0 | 3                | 3 | 2 | 0 |
| : A+1        |   |   |   | : A+1            |   |   |   |
| 7            | 3 | 3 | 0 | 4                | 3 | C | 0 |
| : A+2        |   |   |   | : A+2            |   |   |   |

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### 8.3.13 Leading Separate Numeric String

A leading separate numeric string is a contiguous sequence of bytes in memory. A leading separate numeric string is specified by two attributes: the address *A* of the first byte (containing the sign character), and a length *L*, which is the length of the string in digits and *not* the length of the string in bytes. The number of bytes in a leading separate numeric string is  $L + 1$ .

The sign of a separate leading numeric string is stored in a separate byte. Valid sign bytes are indicated in the following table:

| Sign | Decimal | Hex | ASCII character |
|------|---------|-----|-----------------|
| +    | 43      | 2B  | +               |
| +    | 32      | 20  | {blank}         |
| -    | 45      | 2D  | -               |

The preferred representation for “+” is ASCII “+”. All subsequent bytes contain an ASCII digit character, as indicated in the following table:

| Digit | Decimal | Hex | ASCII character |
|-------|---------|-----|-----------------|
| 0     | 48      | 30  | 0               |
| 1     | 49      | 31  | 1               |
| 2     | 50      | 32  | 2               |
| 3     | 51      | 33  | 3               |
| 4     | 52      | 34  | 4               |
| 5     | 53      | 35  | 5               |
| 6     | 54      | 36  | 6               |
| 7     | 55      | 37  | 7               |
| 8     | 56      | 38  | 8               |
| 9     | 57      | 39  | 9               |

The length *L* of a leading separate numeric string must be in the range 0 to 31 (0 to 31 digits). The value of a zero-length string is zero.

The address *A* of the string specifies the byte of the string containing the sign. Digits of decreasing significance are assigned to bytes of increasing addresses. Thus “+123” is represented as follows:

## Basic Architecture

### 8.3 Data Types

|   |   |   |   |       |
|---|---|---|---|-------|
| 7 | 4 | 3 | 0 |       |
| 2 | B |   |   | : A   |
| 3 | 1 |   |   | : A+1 |
| 3 | 2 |   |   | : A+2 |
| 3 | 3 |   |   | : A+3 |

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The leading separate numeric string with a value of “-123” is represented as follows:

|   |   |   |   |       |
|---|---|---|---|-------|
| 7 | 4 | 3 | 0 |       |
| 2 | D |   |   | : A   |
| 3 | 1 |   |   | : A+1 |
| 3 | 2 |   |   | : A+2 |
| 3 | 3 |   |   | : A+3 |

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#### 8.3.14 Packed Decimal String

A packed decimal string is a contiguous sequence of bytes in memory. A packed decimal string is specified by two attributes: the address A of the first byte of the string and a length L, which is the number of digits in the string and *not* the length of the string in bytes. The bytes of a packed decimal string are divided into two, 4-bit fields (nibbles). Each nibble except the low nibble (bits 3:0) of the last (highest-addressed) byte must contain a decimal digit. The low nibble of the highest-addressed byte must contain a sign. The representation for the digits and sign is indicated as follows:

| Digit or Sign | Decimal         | Hexadecimal |
|---------------|-----------------|-------------|
| 0             | 0               | 0           |
| 1             | 1               | 1           |
| 2             | 2               | 2           |
| 3             | 3               | 3           |
| 4             | 4               | 4           |
| 5             | 5               | 5           |
| 6             | 6               | 6           |
| 7             | 7               | 7           |
| 8             | 8               | 8           |
| 9             | 9               | 9           |
| +             | 10,12,14, or 15 | A,C,E, or F |
| -             | 11 or 13        | B or D      |

The preferred sign representation is 12 for “+” and 13 for “-”. The length L is the number of digits in the packed decimal string (not counting the sign); L must be

in the range 0 to 31. When the number of digits is odd, the digits and the sign fit into a string of bytes whose length is defined by the following equation:  $L/2$  (integer part only) + 1. When the number of digits is even, it is required that an extra “0” digit appear in the high nibble (bits 7:4) of the first byte of the string. Again, the length in bytes of the string is  $L/2 + 1$ .

The address A of the string specifies the byte of the string containing the most-significant digit in its high nibble. Digits of decreasing significance are assigned to increasing byte addresses and from high nibble to low nibble within a byte. Thus, “+123” has a length of 3 and is represented as follows:

|   |    |   |   |       |
|---|----|---|---|-------|
| 7 | 4  | 3 | 0 |       |
| 1 | 2  |   |   | : A   |
| 3 | 12 |   |   | : A+1 |

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The packed decimal number “-12” has a length of 2 and is represented as follows:

|   |    |   |   |       |
|---|----|---|---|-------|
| 7 | 4  | 3 | 0 |       |
| 0 | 1  |   |   | : A   |
| 2 | 13 |   |   | : A+1 |

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## 8.4 Processor Status Longword (PSL)

The processor status longword (PSL) consists of a set of processor state variables associated with each process. Bits 31:16 of the PSL have privileged status. For information on this part of the PSL, refer to the *VAX Architecture Reference Manual*. Bits 15:0 of the PSL are referred to separately as the processor status word (PSW).

The format of the PSL is as follows:

|    |    |     |    |    |     |     |    |     |     |    |    |    |    |   |   |   |   |   |   |   |   |   |
|----|----|-----|----|----|-----|-----|----|-----|-----|----|----|----|----|---|---|---|---|---|---|---|---|---|
| 31 | 30 | 29  | 28 | 27 | 26  | 25  | 24 | 23  | 22  | 21 | 20 | 16 | 15 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| C  | T  |     | F  | I  | CUR | PRV | M  |     |     |    |    |    |    | D | F | I |   |   |   |   |   |   |
| M  | P  | MBZ | P  | S  | MOD | MOD | B  | IPL | MBZ |    |    |    |    | V | U | V | T | N | Z | V | C |   |

ZK-1139A-GE

The processor status word (PSW), bits 0 to 15 of the processor status longword, contains the following codes:

- The condition codes, which give information on the results produced by previous VAX scalar instructions.
- The exception enable codes, which control the processor action on certain VAX scalar exception conditions (see Appendix E).

## Basic Architecture

### 8.4 Processor Status Longword (PSL)

The condition codes are UNPREDICTABLE when they are affected by UNPREDICTABLE results. The VAX procedure call instructions conditionally set the IV and DV enable bits, clear the FU enable bit, and leave the T enable bit unchanged at procedure entry.

The PSL is saved automatically on the stack when an exception or interrupt occurs and is saved in the process control block on a process context switch. The PSL can also be read by the MOVPSL instruction.

The vector processor does not use PSL(IV) and PSL(FU) to enable integer overflow and floating underflow exception checking for vector instructions. Also, vector instruction exceptions do not affect the values of the PSL condition codes bits.

#### 8.4.1 C Bit

The C (carry) condition code bit, when set, indicates that the last instruction that affected C had a carry out of the most-significant bit of the result, or a borrow into the most-significant bit. When C is clear, no carry or borrow occurred.

#### 8.4.2 V Bit

The V (overflow) condition code bit, when set, indicates that the last instruction that affected V produced a result whose magnitude was too large to be properly represented in the operand that received the result, or that there was a conversion error. When V is clear, no overflow or conversion error occurred.

#### 8.4.3 Z Bit

The Z (zero) condition code, when set, indicates that the last instruction that affected Z produced a result that was zero. When Z is clear, the result was nonzero.

#### 8.4.4 N Bit

The N (negative) condition code bit, when set, indicates that the last instruction that affected N produced a negative result. When N is clear, the result was positive (or zero).

#### 8.4.5 T Bit

The T (trace) bit, when set at the beginning of an instruction, causes the TP bit in the Processor Status Longword to be set. When TP is set at the end of an instruction, a trace fault is taken before the execution of the next instruction. See Appendix E for additional information on the TP bit and the trace fault.

#### 8.4.6 IV Bit

The IV (integer overflow) bit, when set, forces an integer overflow trap after execution of an instruction that produced an integer result that overflowed or had a conversion error. When IV is clear, no integer overflow trap occurs. (However, the condition code V bit is still set.)

#### 8.4.7 FU Bit

The FU (floating underflow) bit, when set, forces a floating underflow fault if the result of a floating-point instruction is too small in magnitude to be represented in the result operand. When FU is clear, no underflow fault occurs.

### 8.4.8 DV Bit

The DV (decimal overflow) bit, when set, forces a decimal overflow trap after execution of an instruction that produced an overflowed decimal (numeric string, or packed decimal) result or had a conversion error. When DV is clear, no trap occurs. (However, the condition code V bit is still set.)

## 8.5 Permanent Exception Enables

The processor action on certain exception conditions is not controlled by bits in the PSW. Traps or faults always result from these exception conditions.

### 8.5.1 Divide by Zero

A divide-by-zero trap is forced after the execution of an integer or decimal division instruction that has a zero divisor. A fault occurs on a floating-point division instruction that has a zero divisor.

### 8.5.2 Floating Overflow

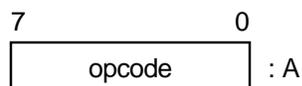
A floating overflow fault is forced after the execution of a floating-point instruction that produced a result too large to be represented in the result operand.

## 8.6 Instruction and Addressing Mode Formats

The following sections describe the formats for instruction opcodes and for the operand specifiers used with the various addressing modes.

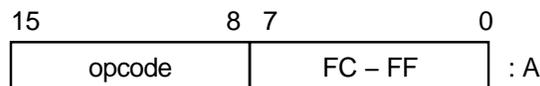
### 8.6.1 Opcode Formats

An instruction is specified by the byte address A of its opcode.



ZK-1140A-GE

The opcode may extend over 2 bytes; the length depends on the contents of the byte at address A. If, and only if, the value of the byte is FC (hex) to FF (hex), the opcode is 2 bytes long.



ZK-1141A-GE

### 8.6.2 Operand Specifiers

Each instruction takes a specific sequence of operand specifier types. An operand specifier type conceptually has two attributes: the access type and the data type.

The access types include the following:

1. Read—The specified operand is read only.
2. Write—The specified operand is written only.
3. Modify—The specified operand is read, potentially modified, and written. This operation is not performed under a memory interlock.

## Basic Architecture

### 8.6 Instruction and Addressing Mode Formats

4. Address—The address of the specified operand in the form of a longword is the actual instruction operand. The specified operand is not accessed directly, although the instruction may subsequently use the address to access that operand.
5. Variable bit field base address—This access type is a special variant of the address access type. Variable bit field base address type is the same as address access type except for register mode. In register mode, the field is contained in register *n*, designated by the operand specifier (or register *n*+1 concatenated with register *n*).
6. Branch—No operand is accessed. The operand specifier itself is a branch displacement.

Access types 1 to 5 are general mode addressing. Type 6 is branch mode addressing.

The data types include the following:

- Byte
- Word
- Longword and F\_floating (equivalent for addressing mode considerations)
- Quadword, D\_floating, and G\_floating (equivalent for addressing mode considerations)
- Octaword and H\_floating (equivalent for addressing mode considerations)

For the address and branch access types, which do not directly reference operands, the data type indicates:

- Address—the operand size to be used in the address calculation in autoincrement, autodecrement, and index modes
- Branch—the size of the branch displacement

### 8.7 General Addressing Mode Formats

The following sections describe the operand specifier formats for the general addressing modes. For descriptions and examples of the use of the general addressing modes, see Chapter 5.

In Section 8.8, Table 8–5 is a summary of general register addressing and Table 8–6 is a summary of program counter addressing.

#### Notation for Describing Addressing Modes

The following notation describes the addressing modes:

|            |   |
|------------|---|
| +          | Addition  |
| -          | Subtraction                                     |
| *          | Multiplication                                  |
| <-         | Is replaced by                                  |
| =          | Is defined as                                   |
| '          | Concatenation                                   |
| Rn or R[n] | The contents of register <i>n</i>               |
| PC or SP   | The contents of register 15 or 14, respectively |

|         |   |
|---------|---|
| (x)     | The contents of a location in memory whose address is x |
| { }     | Arithmetic parentheses that indicate precedence         |
| SEXT(x) | x is sign extended to size of operand needed            |
| ZEXT(x) | x is zero extended to size of operand needed            |
| OA      | Operand address   |
| !       | Comment delimiter                                       |

---

**Note**

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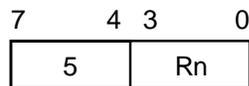
In the formal descriptions of the addressing modes, the symbol for a register (for example, Rn or PC) always means the contents of the register (for example, the contents of register n or the contents of register 15). However, in text, when there is no ambiguity, the symbol for a register is often used as the name of a register (for example, Rn may be used for the name of register n, and PC may be used for the name of register 15).

---

Each general mode addressing description includes the definition of the operand address and the specified operand. For operand specifiers of address access type, the operand address is the actual instruction operand. For other access types, the specified operand is the instruction operand. The branch mode addressing description includes the definition of the branch address.

### 8.7.1 Register Mode

The operand specifier format is as follows:



ZK-1142A-GE

No specifier extension follows.

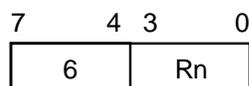
In register mode addressing, the operand is the contents of either register n or (for quadword, D\_floating, and certain field operands) register n+1 concatenated with register n.

|           |                               |                     |
|-----------|-------------------------------|---------------------|
| operand = | Rn                            | ! If 1 register     |
|           | or                            |                     |
|           | R[n+1] ' Rn                   | ! If two registers  |
|           | or                            |                     |
|           | R[n+3] ' R[n+2] ' R[n+1] ' Rn | ! If four registers |

The assembler notation for register mode is Rn.

### 8.7.2 Register Deferred Mode

The operand specifier format is as follows:



ZK-1143A-GE

## Basic Architecture

### 8.7 General Addressing Mode Formats

No specifier extension follows.

In register deferred mode addressing, the address of the operand is the contents of register n.

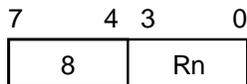
$$OA = Rn$$

$$\text{operand} = (OA)$$

The assembler notation for register deferred mode is (Rn).

#### 8.7.3 Autoincrement Mode

The operand specifier format is as follows:



ZK-1144A-GE

No specifier extension follows. If Rn denotes the PC, immediate data follows, and the mode is termed immediate mode.

In autoincrement mode addressing, the address of the operand is the contents of register n. After the operand address is determined, the size of the operand in bytes (1 for byte; 2 for word; 4 for longword and F\_floating; 8 for quadword, G\_floating, and D\_floating; and 16 for octaword and H\_floating) is added to the contents of register n, and the contents of register n are replaced by the result.

$$OA = Rn$$

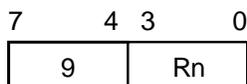
$$Rn \leftarrow Rn + \text{size}$$

$$\text{operand} = (OA)$$

The assembler notation for autoincrement mode is (Rn)+. For immediate mode, the notation is I^#constant, where constant is the immediate data that follows.

#### 8.7.4 Autoincrement Deferred Mode

The operand specifier format is as follows:



ZK-1145A-GE

No specifier extension follows. If Rn denotes the PC, a longword address follows and the mode is termed absolute mode.

In autoincrement deferred mode addressing, the address of the operand is the contents of a longword whose address is the contents of register n. After the operand address is determined, 4 (the size in bytes of a longword address) is added to the contents of register n and the contents of register n are replaced by the result.

$$OA = (Rn)$$

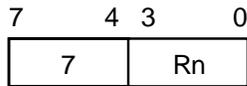
$$Rn \leftarrow Rn + 4$$

operand = (OA)

The assembler notation for autoincrement deferred mode is @(Rn)+. For absolute mode, the notation is @#address, where address is the longword that follows.

### 8.7.5 Autodecrement Mode

The operand specifier format is as follows:



ZK-1146A-GE

No specifier extension follows.

In autodecrement mode addressing, the size of the operand in bytes (1 for byte; 2 for word; 4 for longword and F\_floating; 8 for quadword, G\_floating, and D\_floating; and 16 for octaword and H\_floating) is subtracted from the contents of register n, and the contents of register n are replaced by the result. The updated contents of register n are the address of the operand.

$Rn \leftarrow Rn - \text{size}$

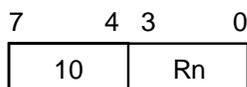
OA = Rn

operand = (OA)

The assembler notation for autodecrement mode is -(Rn).

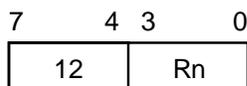
### 8.7.6 Displacement Mode

There are three operand specifier formats.



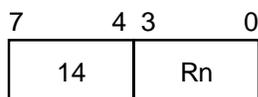
ZK-1147A-GE

The specifier extension is a signed byte displacement that follows the operand specifier. This is the byte displacement mode.



ZK-1148A-GE

The specifier extension is a signed word displacement that follows the operand specifier. This is the word displacement mode.



ZK-1149A-GE

## Basic Architecture

### 8.7 General Addressing Mode Formats

The specifier extension is a longword displacement that follows the operand specifier. This is the longword displacement mode.

In displacement mode addressing, the displacement (after it is sign extended to 32 bits, if it is byte or word displacement) is added to the contents of register n, and the result is the operand address.

$$OA = Rn + \text{SEXT}(\text{displ}) \quad ! \text{ If byte or word displacement}$$

or

$$Rn + \text{displ} \quad ! \text{ If longword displacement}$$

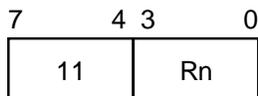
$$\text{operand} = (OA)$$

If  $Rn$  denotes PC, the updated contents of the PC are used. The address in the PC (the updated contents) is the address of the first byte beyond the specifier extension.

The assembler notation for byte, word, and long displacement mode is  $B^D(Rn)$ ,  $W^D(Rn)$ , and  $L^D(Rn)$ , respectively, where  $D$  = displacement.

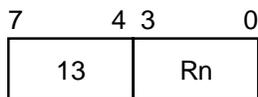
#### 8.7.7 Displacement Deferred Mode

There are three operand specifier formats.



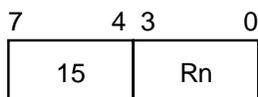
ZK-1150A-GE

The specifier extension is a signed byte displacement that follows the operand specifier. This is the byte displacement deferred mode.



ZK-1151A-GE

The specifier extension is a signed word displacement that follows the operand specifier. This is the word displacement deferred mode.



ZK-1152A-GE

The specifier extension is a longword displacement that follows the operand specifier. This is the longword displacement deferred mode.

In displacement deferred mode addressing, the displacement (after it is sign extended to 32 bits, if it is byte or word displacement) is added to the contents of register n, and the result is the address of a longword whose contents are the operand address.

$OA = (Rn + SEXT(displ))$  ! If byte or word displacement

or

$(Rn + displ)$  ! If longword displacement

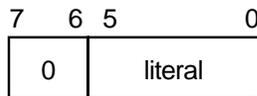
operand = (OA)

If  $Rn$  denotes PC, the updated contents of the PC are used. The address in the PC (the updated contents) is the address of the first byte beyond the specifier extension.

The assembler notation for byte, word, and longword displacement deferred mode is  $@B^D(Rn)$ ,  $@W^D(Rn)$ , and  $@L^D(Rn)$ , respectively, where  $D = \text{displacement}$ .

### 8.7.8 Literal Mode

The operand specifier format is as follows:



ZK-1153A-GE

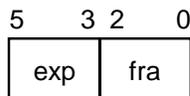
No specifier extension follows.

For operands of data type byte, word, longword, quadword, and octaword, the operand is the zero extension of the 6-bit literal field.

operand = ZEXT(literal)

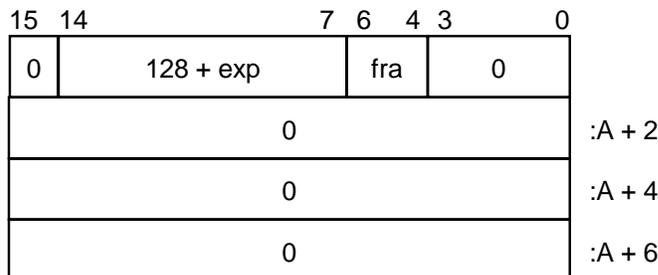
Thus, for these data types, you may use literal mode for values in the range 0 to 63.

For operands of data type  $F\_floating$ ,  $G\_floating$ ,  $D\_floating$ , and  $H\_floating$ , the 6-bit literal field is composed of two, 3-bit fields. These fields are illustrated in the following diagram, where  $exp$  is exponent and  $fra$  is fraction:



ZK-1154A-GE

You use the exponent and fraction fields to form an  $F\_floating$  or  $D\_floating$  operand as follows:



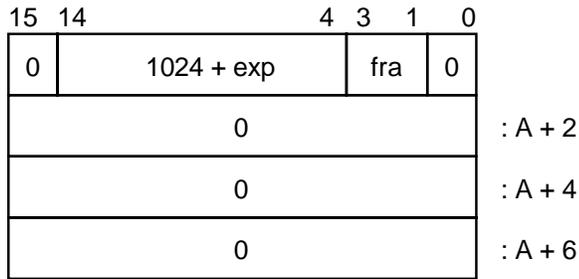
ZK-1155A-GE

Note that bits 63:32 are not present in an  $F\_floating$  operand.

## Basic Architecture

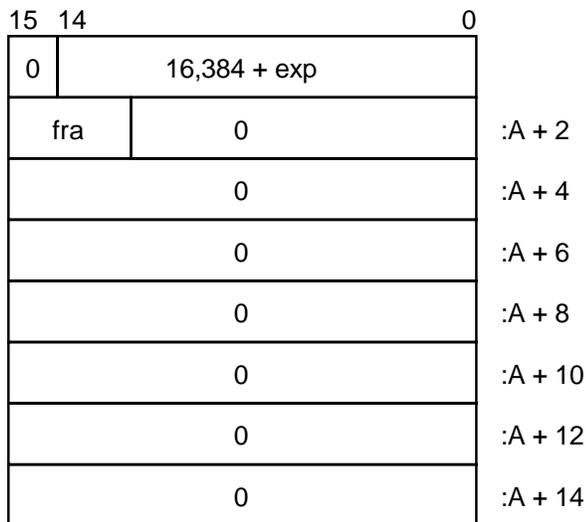
### 8.7 General Addressing Mode Formats

You use the exponent and fraction fields to form a G\_floating operand as follows:



ZK-1156A-GE

You use the exponent and fraction fields to form an H\_floating operand as follows:



ZK-1157A-GE

The range of values available is given in Table 8-3 and Table 8-4 in both decimal and rational number notation.

**Table 8-3 Floating-Point Literals Expressed as Decimal Numbers**

| Exponent | 0    | 1      | 2     | 3      | 4    | 5      | 6     | 7      |
|----------|------|--------|-------|--------|------|--------|-------|--------|
| 0        | 0.5  | 0.5625 | 0.625 | 0.6875 | 0.75 | 0.8125 | 0.875 | 0.9375 |
| 1        | 1.0  | 1.125  | 1.25  | 1.37   | 1.5  | 1.625  | 1.75  | 1.875  |
| 2        | 2.0  | 2.25   | 2.5   | 2.75   | 3.0  | 3.25   | 3.5   | 3.75   |
| 3        | 4.0  | 4.5    | 5.0   | 5.5    | 6.0  | 6.5    | 7.0   | 7.5    |
| 4        | 8.0  | 9.0    | 10.0  | 11.0   | 12.0 | 13.0   | 14.0  | 15.0   |
| 5        | 16.0 | 18.0   | 20.0  | 22.0   | 24.0 | 26.0   | 28.0  | 30.0   |
| 6        | 32.0 | 36.0   | 40.0  | 44.0   | 48.0 | 52.0   | 56.0  | 60.0   |
| 7        | 64.0 | 72.0   | 80.0  | 88.0   | 96.0 | 104.0  | 112.0 | 120.0  |

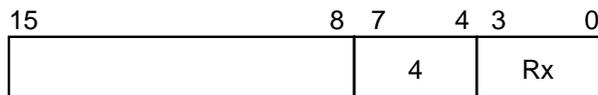
**Table 8–4 Floating-Point Literals Expressed as Rational Numbers**

| Exponent | 0   | 1     | 2     | 3     | 4     | 5     | 6     | 7     |
|----------|-----|-------|-------|-------|-------|-------|-------|-------|
| 0        | 1/2 | 9/16  | 5/8   | 11/16 | 3/4   | 13/16 | 7/8   | 15/16 |
| 1        | 1   | 1-1/8 | 1-1/4 | 1-3/8 | 1-1/2 | 1-5/8 | 1-3/4 | 1-7/8 |
| 2        | 2   | 2-1/4 | 2-1/2 | 2-3/4 | 3     | 3-1/4 | 3-1/2 | 3-3/4 |
| 3        | 4   | 4-1/2 | 5     | 5-1/2 | 6     | 6-1/2 | 7     | 7-1/2 |
| 4        | 8   | 9     | 10    | 11    | 12    | 13    | 14    | 15    |
| 5        | 16  | 18    | 20    | 22    | 24    | 26    | 28    | 30    |
| 6        | 32  | 36    | 40    | 44    | 48    | 52    | 56    | 60    |
| 7        | 64  | 72    | 80    | 88    | 96    | 104   | 112   | 120   |

The assembler notation for literal mode is  $S^{\#}\text{literal}$ .

### 8.7.9 Index Mode

The operand specifier format is as follows:



ZK-1158A-GE

Bits 15:8 contain a second operand specifier (termed the base operand specifier) for any of the addressing modes except register, literal, or index. The specification of register, literal, or index addressing mode results in an illegal addressing mode fault (see Appendix E). If the base operand specifier requires it, a specifier extension immediately follows. The base operand specifier is subject to the same restrictions as would apply if it were used alone. If the use of some particular specifier is illegal (that is, causes a fault or UNPREDICTABLE behavior) under some circumstances, then that specifier is similarly illegal as a base operand specifier in index mode under the same circumstances.

The operand to be specified by index mode addressing is termed the primary operand. You normally use the base operand specifier to determine an operand address. This address is termed the base operand address (BOA). The address of the primary operand specified is determined by multiplying the contents of the index register  $x$  by the size of the primary operand in bytes (1 for byte; 2 for word; 4 for longword and  $F_{\text{floating}}$ ; 8 for quadword,  $D_{\text{floating}}$ , and  $G_{\text{floating}}$ ; and 16 for octaword and  $H_{\text{floating}}$ ), adding BOA, and taking the result.

$$OA = BOA + \{\text{size} * (Rx)\}$$

$$\text{operand} = (OA)$$

If the base operand specifier is for autoincrement or autodecrement mode, the increment or decrement size is the size in bytes of the primary operand.

Certain restrictions are placed on the index register  $x$ . You cannot use the PC as an index register. If you use it, a reserved addressing mode fault occurs (see Appendix E). If the base operand specifier is for an addressing mode that results in register modification (that is, autoincrement mode, autodecrement mode, or autoincrement deferred mode), the same register cannot be the index register. If it is, the primary operand address is UNPREDICTABLE.

## Basic Architecture

### 8.7 General Addressing Mode Formats

The names of the addressing modes resulting from index mode addressing are formed by adding the suffix “indexed” to the addressing mode of the base operand specifier. The following list gives the names and assembler notation (the index register is designated Rx to distinguish it from the register Rn in the base operand specifier):

- Register deferred indexed— (Rn)[Rx]
- Autoincrement indexed— (Rn)+[Rx]  
or  
Immediate indexed— I^#constant[Rx] (Immediate indexed is recognized by the assembler, but is not generally useful. Note that the operand address is independent of the value of the constant.)
- Autoincrement deferred indexed— @(Rn)+[Rx]  
or  
Absolute indexed— @#address[Rx]
- Autodecrement indexed— -(Rn)[Rx]
- Byte, word, or longword displacement indexed— B^D(Rn)[Rx], W^D(Rn)[Rx], or L^D(Rn)[Rx]
- Byte, word, or longword displacement deferred indexed— @B^D(Rn)[Rx], @W^D(Rn)[Rx], or @L^D(Rn)[Rx]

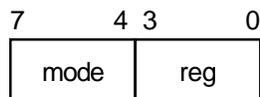
### 8.8 Summary of General Mode Addressing

This section provides summaries of general register and program counter (PC) addressing.

Table 8–5 is a summary of general register addressing and Table 8–6 is a summary of PC addressing.

#### 8.8.1 General Register Addressing

The general register addressing format is as follows:



ZK-1159A-GE

## Basic Architecture

### 8.8 Summary of General Mode Addressing

**Table 8–5 General Register Addressing**

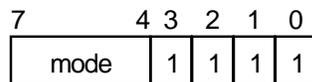
| Hex | Dec | Name                              | Assembler  | r m w a v | PC | SP | AP<br>FP | Can Be<br>Indexed? |
|-----|-----|-----------------------------------|------------|-----------|----|----|----------|--------------------|
| 0–3 | 0–3 | Literal                           | S^#literal | y f f f f | —  | —  | —        | f                  |
| 4   | 4   | Indexed                           | i[Rx]      | y y y y y | f  | y  | y        | f                  |
| 5   | 5   | Register                          | Rn         | y y y f y | u  | uq | uo       | f                  |
| 6   | 6   | Register deferred                 | (Rn)       | y y y y y | u  | y  | y        | y                  |
| 7   | 7   | Autodecrement                     | -(Rn)      | y y y y y | u  | y  | y        | ux                 |
| 8   | 8   | Autoincrement                     | (Rn)+      | y y y y y | p  | y  | y        | ux                 |
| 9   | 9   | Autoincrement<br>deferred         | @(Rn)+     | y y y y y | p  | y  | y        | ux                 |
| A   | 10  | Byte displacement                 | B^D(Rn)    | y y y y y | p  | y  | y        | y                  |
| B   | 11  | Byte displacement<br>deferred     | @B^D(Rn)   | y y y y y | p  | y  | y        | y                  |
| C   | 12  | Word displacement                 | W^D(Rn)    | y y y y y | p  | y  | y        | y                  |
| D   | 13  | Word displacement<br>deferred     | @W^D(Rn)   | y y y y y | p  | y  | y        | y                  |
| E   | 14  | Longword displacement             | L^D(Rn)    | y y y y y | p  | y  | y        | y                  |
| F   | 15  | Longword displacement<br>deferred | @L^D(Rn)   | y y y y y | p  | y  | y        | y                  |

**Key:**

D—Displacement  
 i—Any indexable addressing mode  
 - —Logically impossible  
 f—Reserved addressing mode fault  
 p—Program Counter addressing  
 u—UNPREDICTABLE  
 uq—UNPREDICTABLE for quadword, octaword, D\_floating, H\_floating, and G\_floating, (and field if position and size greater than 32)  
 uo—UNPREDICTABLE for octaword and H\_floating  
 ux—UNPREDICTABLE for index register same as base register  
 y—Yes, always valid addressing mode  
 r—Read access  
 m—Modify access  
 w—Write access  
 a—Address access  
 v—Field access

### 8.8.2 Program Counter Addressing

The program counter addressing format is as follows:



ZK–1326A–GE

## Basic Architecture

### 8.8 Summary of General Mode Addressing

Table 8–6 Program Counter Addressing

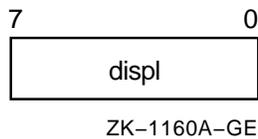
| Hex | Dec | Name                          | Assembler   | r m w a v | Can Be Indexed? |
|-----|-----|-------------------------------|-------------|-----------|-----------------|
| 8   | 8   | Immediate                     | I^#constant | y u u y y | u               |
| 9   | 9   | Absolute                      | @#address   | y y y y y | y               |
| A   | 10  | Byte relative                 | B^address   | y y y y y | y               |
| B   | 11  | Byte relative<br>deferred     | @B^address  | y y y y y | y               |
| C   | 12  | Word relative                 | W^address   | y y y y y | y               |
| D   | 13  | Word relative<br>deferred     | @W^address  | y y y y y | y               |
| E   | 14  | Longword<br>relative          | L^address   | y y y y y | y               |
| F   | 15  | Longword<br>relative deferred | @L^address  | y y y y y | y               |

**Key:**

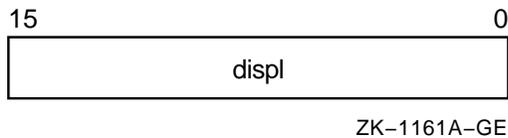
u—UNPREDICTABLE  
y—Yes, always valid addressing mode  
r—Read access  
m—Modify access  
w—Write access  
a—Address access  
v—Field access

### 8.9 Branch Mode Addressing Formats

There are two operand specifier formats.



The operand specifier is a signed byte displacement.



The operand specifier is a signed word displacement.

In branch displacement addressing, the byte or word displacement is sign extended to 32 bits and added to the updated address in the PC. The updated address in the PC is the location of the first byte beyond the operand specifier. The result is the branch address A.

$$A = PC + \text{SEXT}(\text{displ})$$

The assembler notation for byte and word branch displacement addressing is A, where A is the branch address. Note that you must use the branch address, and not the displacement.

---

# VAX Instruction Set

The following sections describe the native-mode instruction set. The instructions are divided into groups according to their function and are listed alphabetically within each group.

## 9.1 Introduction to the VAX Instruction Set

This section describes the instructions generally used by all software across all implementations of the VAX architecture.

You can find a more complete description of the instruction set in the *VAX Architecture Reference Manual*. The *VAX Architecture Reference Manual* also contains information on instructions that are generally used by privileged software and are specific to specialized portions of the VAX architecture, such as memory management, interrupts and exceptions, process dispatching, and processor registers.

A list of instructions and opcode assignments appears in Appendix D.

## 9.2 Instruction Descriptions

The instruction set is divided into the following 12 major sections:

- Integer arithmetic and logical
- Address
- Variable-length bit field
- Control
- Procedure call
- Miscellaneous
- Queue
- Floating point
- Character string
- Cyclic redundancy check (CRC)
- Decimal string
- Edit

Within each major section, instructions that are closely related are combined into groups and described together. The instruction group description is composed of the following:

- The group name.

## VAX Instruction Set

### 9.2 Instruction Descriptions

- The format of each instruction in the group, including the name and type of each instruction operand specifier and the order in which it appears in memory. Operand specifiers from left to right appear in increasing memory addresses.
- The operation of the instruction. The operation is given as a sequence of pseudocode statements in an ALGOL-like syntax. Each VAX processor may implement the instruction in different or more efficient ways, but each processor gives results consistent with the pseudocode, English descriptions, and notes.
- The effect on condition codes.
- Exceptions specific to the instruction. Exceptions that are generally possible for all instructions (for example, illegal or reserved addressing mode, T-bit, and memory management violations) are not listed.
- The opcodes, mnemonics, and names of each instruction in the group. The opcodes are given in hexadecimal.
- A description, in English, of the instruction.
- Optional notes on the instruction and programming examples.

#### Operand Specifier Notation

Operand specifiers are described as follows:

name . access-type data-type

#### name

A mnemonic name for the operand in the context of the instruction. The name is often abbreviated.

#### access-type

A letter denoting the operand specifier access type:

- a Calculate the effective address of the specified operand. Address is returned in a longword that is the actual instruction operand. Context of address calculation is given by **data-type**; that is, size to be used in autoincrement, autodecrement, and indexing.
- b No operand reference. Operand specifier is a branch displacement. Size of branch displacement is given by **data-type**.
- m Operand is read, potentially modified, and written. Note that this is *not* an indivisible memory operation. Also note that if the operand is not actually modified, it may not be written back. However, modify type operands are always checked for both read and write accessibility.
- r Operand is read only.
- v Calculate the effective address of the specified operand. If the effective address is in memory, the address is returned in a longword that is the actual instruction operand. Context of address calculation is given by **data-type**. If the effective address is  $R_n$ , the operand is in  $R_n$  or  $R[n+1]R_n$ .
- w Operand is written only.

#### data-type

A letter denoting the data type of the operand:

- b Byte
- d D\_floating

## VAX Instruction Set 9.2 Instruction Descriptions

|   |   |
|---|---|
| f | F_floating                                |
| g | G_floating                                |
| h | H_floating                                |
| l | Longword                                  |
| o | Octaword                                  |
| q | Quadword                                  |
| w | Word                                      |
| x | First data type specified by instruction  |
| y | Second data type specified by instruction |

### Operation Description Notation

The operation of an instruction is given as a sequence of control and assignment statements in an ALGOL-like syntax. No attempt is made to formally define the syntax; it is assumed to be familiar to the reader. The notation used is an extension of the notation introduced in Section 8.7.

|                   |  |
|-------------------|--|
| +                 | Addition   |
| -                 | Subtraction, unary minus   |
| *                 | Multiplication   |
| /                 | Division (quotient only)   |
| **                | Exponentiation   |
| ,                 | Concatenation  |
| <-                | Is replaced by   |
| =                 | Is defined as  |
| Rn or R[n]        | Contents of register Rn  |
| PC, SP, FP, or AP | The contents of register R15, R14, R13, or R12, respectively   |
| PSW               | The contents of the processor status word  |
| PSL               | The contents of the processor status longword  |
| (x)               | Contents of memory location whose address is x   |
| (x)+              | Contents of memory location whose address is x; x incremented by the size of operand referenced at x   |
| -(x)              | x decremented by size of operand to be referenced at x; contents of memory location whose address is x |
| <x:y>             | A modifier that delimits an extent from bit position x to bit position y inclusive                     |
| <x1,x2,...,xn>    | A modifier that enumerates bits x1,x2,...,xn   |
| { }               | Arithmetic parentheses used to indicate precedence   |
| AND               | Logical AND  |
| OR                | Logical OR   |
| XOR               | Logical XOR  |
| NOT               | Logical (one's) complement   |
| LSS               | Less than signed   |
| LSSU              | Less than unsigned   |
| LEQ               | Less than or equal signed  |

## VAX Instruction Set

### 9.2 Instruction Descriptions

|           |  |
|-----------|--|
| LEQU      | Less than or equal unsigned  |
| EQL       | Equal signed   |
| EQLU      | Equal unsigned   |
| NEQ       | Not equal signed   |
| NEQU      | Not equal unsigned   |
| GEQ       | Greater than or equal signed   |
| GEQU      | Greater than or equal unsigned   |
| GTR       | Greater than signed  |
| GTRU      | Greater than unsigned  |
| SEXT(x)   | x is sign extended to size of operand needed                               |
| ZEXT(x)   | x is zero extended to size of operand needed                               |
| REM(x,y)  | Remainder of x divided by y, such that x/y and REM(x,y) have the same sign |
| MINU(x,y) | Minimum unsigned of x and y  |
| MAXU(x,y) | Maximum unsigned of x and y  |

Use the following conventions:

- Other than alterations caused by (x)+, or -(x), and the advancement of the program counter (PC), only operands or portions of operands appearing on the left side of assignment statements are affected.
- No operator precedence is assumed, except that replacement (<-) has the lowest precedence. Precedence is indicated explicitly by { }.
- All arithmetic, logical, and relational operators are defined in the context of their operands. For example, “+” applied to floating operands means a floating add, while “+” applied to byte operands is an integer byte add. Similarly, “LSS” is a floating comparison when applied to floating operands, while “LSS” is an integer byte comparison when applied to byte operands.
- Instruction operands are evaluated according to the operand specifier conventions (see Chapter 8). The order in which operands appear in the instruction description has no effect on the order of evaluation.
- Condition codes generally indicate the effect of an operation on the value of actual stored results, not on “true” results (which might be generated internally to greater precision). For example, two positive integers can be added together and the sum stored as a negative value because of overflow. The condition codes indicate a negative value even though the “true” result is clearly positive.

### 9.2.1 Integer Arithmetic and Logical Instructions

The following instructions are described in this section:

|     | Description and Opcode   | Number of Instructions |
|-----|--|------------------------|
| 1.  | Add Aligned Word<br>ADAWI add.rw, sum.mw                                 | 1                      |
| 2.  | Add 2 Operand<br>ADD{B,W,L}2 add.rx, sum.mx                              | 3                      |
| 3.  | Add 3 Operand<br>ADD{B,W,L}3 add1.rx, add2.rx, sum.wx                    | 3                      |
| 4.  | Add with Carry<br>ADWC add.rl, sum.ml                                    | 1                      |
| 5.  | Arithmetic Shift<br>ASH{L,Q} cnt.rb, src.rx, dst.wx                      | 2                      |
| 6.  | Bit Clear 2 Operand<br>BIC{B,W,L}2 mask.rx, dst.mx                       | 3                      |
| 7.  | Bit Clear 3 Operand<br>BIC{B,W,L}3 mask.rx, src.rx, dst.wx               | 3                      |
| 8.  | Bit Set 2 Operand<br>BIS{B,W,L}2 mask.rx, dst.mx                         | 3                      |
| 9.  | Bit Set 3 Operand<br>BIS{B,W,L}3 mask.rx, src.rx, dst.wx                 | 3                      |
| 10. | Bit Test<br>BIT{B,W,L} mask.rx, src.rx                                   | 3                      |
| 11. | Clear<br>CLR{B,W,L,Q,O} dst.wx   | 5                      |
| 12. | Compare<br>CMP{B,W,L} src1.rx, src2.rx                                   | 3                      |
| 13. | Convert<br>CVT{B,W,L}{B,W,L} src.rx, dst.wy<br>All pairs except BB,WW,LL | 6                      |
| 14. | Decrement<br>DEC{B,W,L} dif.mx   | 3                      |
| 15. | Divide 2 Operand<br>DIV{B,W,L}2 divr.rx, quo.mx                          | 3                      |
| 16. | Divide 3 Operand<br>DIV{B,W,L}3 divr.rx, divd.rx, quo.wx                 | 3                      |
| 17. | Extended Divide<br>EDIV divr.rl, divd.rq, quo.wl, rem.wl                 | 1                      |
| 18. | Extended Multiply<br>EMUL mulr.rl, muld.rl, add.rl, prod.wq              | 1                      |
| 19. | Increment<br>INC{B,W,L} sum.mx   | 3                      |
| 20. | Move Complemented<br>MCOM{B,W,L} src.rx, dst.wx                          | 3                      |
| 21. | Move Negated<br>MNEG{B,W,L} src.rx, dst.wx                               | 3                      |
| 22. | Move<br>OV{B,W,L,Q} src.rx, dst.wx                                       | 4                      |

## VAX Instruction Set

### 9.2 Instruction Descriptions

|     | Description and Opcode  | Number of Instructions |
|-----|---|------------------------|
| 23. | Move Zero-Extended<br>MOVZ{B,W,L} src.rx, dst.wy              | 3                      |
| 24. | Multiply 2 Operand<br>MUL{B,W,L}2 mulr.rx, prod.mx            | 3                      |
| 25. | Multiply 3 Operand<br>MUL{B,W,L}3 mulr.rx, muld.rx, prod.wx   | 3                      |
| 26. | Push Long<br>PUSHL src.rl, {-(SP).wl}                         | 1                      |
| 27. | Rotate Long<br>ROTL cnt.rb, src.rl, dst.wl                    | 1                      |
| 28. | Subtract with Carry<br>SBWC sub.rl, dif.ml                    | 1                      |
| 29. | Subtract 2 Operand<br>SUB{B,W,L}2 sub.rx, dif.mx              | 3                      |
| 30. | Subtract 3 Operand<br>SUB{B,W,L}3 sub.rx, min.rx, dif.wx      | 3                      |
| 31. | Test<br>TST{B,W,L} src.rx                                     | 3                      |
| 32. | Exclusive OR 2 Operand<br>XOR{B,W,L}2 mask.rx, dst.mx         | 3                      |
| 33. | Exclusive OR 3 Operand<br>XOR{B,W,L}3 mask.rx, src.rx, dst.wx | 3                      |

---

## ADAWI

Add Aligned Word Interlocked

### Format

opcode    add.rw, sum.mw

### Condition Codes

N    <—    sum LSS 0;  
Z    <—    sum EQL 0;  
V    <—    {integer overflow};  
C    <—    {carry from most-significant bit};

### Exceptions

reserved operand fault  
integer overflow

### Opcodes

58        ADAWI                    Add Aligned Word Interlocked

### Description

The addend operand is added to the sum operand, and the sum operand is replaced by the result. If the sum operand is contained in memory, then the operation is interlocked against interlocked operations to the same address from other processors. The destination must be aligned on a word boundary; that is, bit 0 of the address of the sum operand must be zero. If it is not, a reserved operand fault is taken.

#### Notes

1. Integer overflow occurs if the input operands to the add have the same sign, and the result has the opposite sign. On overflow, the sum operand is replaced by the low-order bits of the true result.
2. If the addend and the sum operands overlap, the result and the condition codes are UNPREDICTABLE.

## ADD

Add

### Format

2operand: opcode add.rx, sum.mx

3operand: opcode add1.rx, add2.rx, sum.wx

### Condition Codes

N ← sum LSS 0;

Z ← sum EQL 0;

V ← {integer overflow};

C ← {carry from most-significant bit};

### Exceptions

integer overflow

### Opcodes

|    |       |                    |
|----|-------|--------------------|
| 80 | ADDB2 | Add Byte 2 Operand |
| 81 | ADDB3 | Add Byte 3 Operand |
| A0 | ADDW2 | Add Word 2 Operand |
| A1 | ADDW3 | Add Word 3 Operand |
| C0 | ADDL2 | Add Long 2 Operand |
| C1 | ADDL3 | Add Long 3 Operand |

### Description

In 2 operand format, the addend operand is added to the sum operand and the sum operand is replaced by the result. In 3 operand format, the addend 1 operand is added to the addend 2 operand and the sum operand is replaced by the result.

#### Note

Integer overflow occurs if the input operands to the add have the same sign and the result has the opposite sign. On overflow, the sum operand is replaced by the low-order bits of the true result.

---

## ADWC

Add with Carry

### Format

opcode    add.rl, sum.ml

### Condition Codes

N     $\leftarrow$     sum LSS 0;  
 Z     $\leftarrow$     sum EQL 0;  
 V     $\leftarrow$     {integer overflow};  
 C     $\leftarrow$     {carry from most-significant bit};

### Exceptions

integer overflow

### Opcodes

D8        ADWC                    Add with Carry

### Description

The contents of the condition code C-bit and the addend operand are added to the sum operand and the sum operand is replaced by the result.

#### Notes

1. On overflow, the sum operand is replaced by the low-order bits of the true result.
2. The two additions in the operation are performed simultaneously.

## ASH

Arithmetic Shift

### Format

opcode cnt.rb, src.rx, dst.wx

### Condition Codes

N ← dst LSS 0;  
Z ← dst EQL 0;  
V ← {integer overflow};  
C ← 0;

### Exceptions

integer overflow

### Opcodes

|    |      |                       |
|----|------|-----------------------|
| 78 | ASHL | Arithmetic Shift Long |
| 79 | ASHQ | Arithmetic Shift Quad |

### Description

The source operand is arithmetically shifted by the number of bits specified by the count operand and the destination operand is replaced by the result. The source operand is unaffected. A positive count operand shifts to the left, bringing zeros into the least significant bit. A negative count operand shifts to the right, bringing in copies of the most significant (sign) bit into the most significant bit. A zero count operand replaces the destination operand with the unshifted source operand.

#### Notes

1. Integer overflow occurs on a left shift if any bit shifted into the sign bit position differs from the sign bit of the source operand.
2. If **cnt** GTR 32 (ASHL) or **cnt** GTR 64 (ASHQ), the destination operand is replaced by zero.
3. If **cnt** LEQ -31 (ASHL) or **cnt** LEQ -63 (ASHQ), all the bits of the destination operand are copies of the sign bit of the source operand.

---

## BIC

Bit Clear

### Format

2operand: opcode mask.rx, dst.mx

3operand: opcode mask.rx, src.rx, dst.wx

### Condition Codes

N ← dst LSS 0;

Z ← dst EQL 0;

V ← 0;

C ← C;

### Exceptions

None.

### Opcodes

|    |       |                |
|----|-------|----------------|
| 8A | BICB2 | Bit Clear Byte |
| 8B | BICB3 | Bit Clear Byte |
| AA | BICW2 | Bit Clear Word |
| AB | BICW3 | Bit Clear Word |
| CA | BICL2 | Bit Clear Long |
| CB | BICL3 | Bit Clear Long |

### Description

In 2 operand format, the result of the logical AND on the destination operand and the one's complement of the mask operand replaces the destination operand. In 3 operand format, the result of the logical AND on the source operand and the one's complement of the mask operand replaces the destination operand.

# VAX Instruction Set

## BIS

---

### BIS

Bit Set

#### Format

2operand: opcode mask.rx, dst.mx

3operand: opcode mask.rx, src.rx, dst.wx

#### Condition Codes

N ← dst LSS 0;

Z ← dst EQL 0;

V ← 0;

C ← C;

#### Exceptions

None.

#### Opcodes

|    |       |                        |
|----|-------|------------------------|
| 88 | BISB2 | Bit Set Byte 2 Operand |
| 89 | BISB3 | Bit Set Byte 3 Operand |
| A8 | BISW2 | Bit Set Word 2 Operand |
| A9 | BISW3 | Bit Set Word 3 Operand |
| C8 | BISL2 | Bit Set Long 2 Operand |
| C9 | BISL3 | Bit Set Long 3 Operand |

#### Description

In 2 operand format, the result of the logical OR on the mask operand and the destination operand replaces the destination operand. In 3 operand format, the result of the logical OR on the mask operand and the source operand replaces the destination operand.

## BIT

Bit Test

### Format

opcode mask.rx, src.rx

### Condition Codes

N ← tmp LSS 0;  
 Z ← tmp EQL 0;  
 V ← 0;  
 C ← C;

### Exceptions

None.

### Opcodes

|    |      |               |
|----|------|---------------|
| 93 | BITB | Bit Test Byte |
| B3 | BITW | Bit Test Word |
| D3 | BITL | Bit Test Long |

### Description

The logical AND is performed on the mask operand and the source operand. Both operands are unaffected. The only action is to modify condition codes.

## VAX Instruction Set

### CLR

---

## CLR

Clear

### Format

opcode dst.wx

### Condition Codes

N ← 0;  
Z ← 1;  
V ← 0;  
C ← C;

### Exceptions

None.

### Opcodes

|      |      |            |
|------|------|------------|
| 94   | CLRB | Clear Byte |
| B4   | CLRW | Clear Word |
| D4   | CLRL | Clear Long |
| 7C   | CLRQ | Clear Quad |
| 7CFD | CLRO | Clear Octa |

### Description

The destination operand is replaced by zero.

#### Note

CLR<sub>x</sub> **dst** is equivalent to MOV<sub>x</sub> S<sup>#0</sup>, **dst**, but is 1 byte shorter.

## CMP

Compare

### Format

opcode src1.rx, src2.rx

### Condition Codes

N ← src1 LSS src2;  
 Z ← src1 EQL src2;  
 V ← 0;  
 C ← src1 LSSU src2;

### Exceptions

None.

### Opcodes

|    |      |              |
|----|------|--------------|
| 91 | CMPB | Compare Byte |
| B1 | CMPW | Compare Word |
| D1 | CMPL | Compare Long |

### Description

The source 1 operand is compared with the source 2 operand. The only action is to modify the condition codes.

## CVT

Convert

### Format

opcode src.rx, dst.wy

### Condition Codes

N ← dst LSS 0;  
Z ← dst EQL 0;  
V ← {integer overflow};  
C ← 0;

### Exceptions

integer overflow

### Opcodes

|    |       |                      |
|----|-------|----------------------|
| 99 | CVTBW | Convert Byte to Word |
| 98 | CVTBL | Convert Byte to Long |
| 33 | CVTWB | Convert Word to Byte |
| 32 | CVTWL | Convert Word to Long |
| F6 | CVTLB | Convert Long to Byte |
| F7 | CVTLW | Convert Long to Word |

### Description

The source operand is converted to the data type of the destination operand and the destination operand is replaced by the result. Conversion of a shorter data type to a longer one is done by sign extension; conversion of longer data type to a shorter one is done by truncation of the higher-numbered (most significant) bits.

#### Note

Integer overflow occurs if any truncated bits of the source operand are not equal to the sign bit of the destination operand.

---

## DEC

Decrement

### Format

opcode    dif.mx

### Condition Codes

N    <—    dif LSS 0;  
 Z    <—    dif EQL 0;  
 V    <—    {integer overflow};  
 C    <—    {borrow into most significant bit};

### Exceptions

integer overflow

### Opcodes

|    |      |                |
|----|------|----------------|
| 97 | DECB | Decrement Byte |
| B7 | DECW | Decrement Word |
| D7 | DECL | Decrement Long |

### Description

One is subtracted from the difference operand, and the difference operand is replaced by the result.

#### Notes

1. Integer overflow occurs if the largest negative integer is decremented. On overflow, the difference operand is replaced by the largest positive integer.
2. DEC<sub>x</sub> **dif** is equivalent to SUB<sub>x</sub> S<sup>#1</sup>, **dif**, but is 1 byte shorter.

## DIV

Divide

### Format

2operand: opcode divr.rx, quo.mx  
3operand: opcode divr.rx, divd.rx, quo.wx

### Condition Codes

N <— quo LSS 0;  
Z <— quo EQL 0;  
V <— {integer overflow} OR {divr EQL 0};  
C <— 0;

### Exceptions

integer overflow  
divide by zero

### Opcodes

|    |       |                       |
|----|-------|-----------------------|
| 86 | DIVB2 | Divide Byte 2 Operand |
| 87 | DIVB3 | Divide Byte 3 Operand |
| A6 | DIVW2 | Divide Word 2 Operand |
| A7 | DIVW3 | Divide Word 3 Operand |
| C6 | DIVL2 | Divide Long 2 Operand |
| C7 | DIVL3 | Divide Long 3 Operand |

### Description

In 2 operand format, the quotient operand is divided by the divisor operand, and the quotient operand is replaced by the result. In 3 operand format, the dividend operand is divided by the divisor operand, and the quotient operand is replaced by the result.

#### Notes

1. Division is performed so that the remainder has the same sign as the dividend; that is, the result is truncated toward zero. (Note that a remainder of zero is not saved.)
2. Integer overflow occurs only if the largest negative integer is divided by -1. On overflow, operands are affected as in note 3 following.
3. If the divisor operand is zero, then in 2 operand format the quotient operand is not affected; in 3 operand format the quotient operand is replaced by the dividend operand.

---

## EDIV

Extended Divide

### Format

opcode    divr.rl, divd.rq, quo.wl, rem.wl

### Condition Codes

N    <—    quo LSS 0;  
 Z    <—    quo EQL 0;  
 V    <—    {integer overflow} OR {divr EQL 0};  
 C    <—    0;

### Exceptions

integer overflow  
 divide by zero

### Opcodes

7B        EDIV                            Extended Divide

### Description

The dividend operand is divided by the divisor operand, the quotient operand is replaced by the quotient, and the remainder operand is replaced by the remainder.

#### Notes

1. The division is performed such that the remainder operand (unless it is zero) has the same sign as the dividend operand.
2. On overflow, the operands are affected as in note 3, following.
3. If the divisor operand is zero, then the quotient operand is replaced by bits 31:0 of the dividend operand, and the remainder operand is replaced by zero.

## EMUL

Extended Multiply

### Format

opcode    mulr.rl, muld.rl, add.rl, prod.wq

### Condition Codes

N    <—    prod LSS 0;  
Z    <—    prod EQL 0;  
V    <—    0;  
C    <—    0;

### Exceptions

None.

### Opcodes

7A        EMUL                            Extended Multiply

### Description

The multiplicand operand is multiplied by the multiplier operand, giving a double-length result. The addend operand is sign extended to double length and added to the result. The product operand is replaced by the final result.

---

## INC

Increment

### Format

opcode sum.mx

### Condition Codes

N ← sum LSS 0;  
 Z ← sum EQL 0;  
 V ← {integer overflow};  
 C ← {carry from most significant bit};

### Exceptions

integer overflow

### Opcodes

|    |      |                |
|----|------|----------------|
| 96 | INCB | Increment Byte |
| B6 | INCW | Increment Word |
| D6 | INCL | Increment Long |

### Description

One is added to the sum operand and the sum operand is replaced by the result.

#### Notes

1. Arithmetic overflow occurs if the largest positive integer is incremented. On overflow, the sum operand is replaced by the largest negative integer.
2.  $INC_x \text{ sum}$  is equivalent to  $ADD_x S^{\#1}, \text{ sum}$ , but is 1 byte shorter.

## MCOM

Move Complemented

### Format

opcode src.rx, dst.wx

### Condition Codes

N ← dst LSS 0;  
Z ← dst EQL 0;  
V ← 0;  
C ← C;

### Exceptions

None.

### Opcodes

|    |       |                        |
|----|-------|------------------------|
| 92 | MCOMB | Move Complemented Byte |
| B2 | MCOMW | Move Complemented Word |
| D2 | MCOML | Move Complemented Long |

### Description

The destination operand is replaced by the one's complement of the source operand.

---

## MNEG

Move Negated

### Format

opcode src.rx, dst.wx

### Condition Codes

N ← dst LSS 0;  
Z ← dst EQL 0;  
V ← {integer overflow};  
C ← dst NEQ 0;

### Exceptions

integer overflow

### Opcodes

|    |       |                   |
|----|-------|-------------------|
| 8E | MNEGB | Move Negated Byte |
| AE | MNEGW | Move Negated Word |
| CE | MNEGL | Move Negated Long |

### Description

The destination operand is replaced by the negative of the source operand.

#### Note

Integer overflow occurs if the source operand is the largest negative integer (which has no positive counterpart). On overflow, the destination operand is replaced by the source operand.

## VAX Instruction Set

### MOV

---

## MOV

Move

### Format

opcode src.rx, dst.wx

### Condition Codes

N ← dst LSS 0;  
Z ← dst EQL 0;  
V ← 0;  
C ← C;

### Exceptions

None.

### Opcodes

|      |      |           |
|------|------|-----------|
| 90   | MOVB | Move Byte |
| B0   | MOVW | Move Word |
| D0   | MOVL | Move Long |
| 7D   | MOVQ | Move Quad |
| 7DFD | MOV0 | Move Octa |

### Description

The destination operand is replaced by the source operand.

---

## MOVZ

Move Zero-Extended

### Format

opcode src.rx, dst.wy

### Condition Codes

N ← 0;  
 Z ← dst EQL 0;  
 V ← 0;  
 C ← C;

### Exceptions

None.

### Opcodes

|    |        |                                 |
|----|--------|---------------------------------|
| 9B | MOVZBW | Move Zero-Extended Byte to Word |
| 9A | MOVZBL | Move Zero-Extended Byte to Long |
| 3C | MOVZWL | Move Zero-Extended Word to Long |

### Description

For MOVZBW, bits 7:0 of the destination operand are replaced by the source operand; bits 15:8 are replaced by zero. For MOVZBL, bits 7:0 of the destination operand are replaced by the source operand; bits 31:8 are replaced by zero. For MOVZWL, bits 15:0 of the destination operand are replaced by the source operand; bits 31:16 are replaced by zero.

## MUL

Multiply

### Format

2operand: opcode mulr.rx, prod.mx

3operand: opcode mulr.rx, muld.rx, prod.wx

### Condition Codes

N ← prod LSS 0;  
Z ← prod EQL 0;  
V ← {integer overflow};  
C ← 0;

### Exceptions

integer overflow

### Opcodes

|    |       |                         |
|----|-------|-------------------------|
| 84 | MULB2 | Multiply Byte 2 Operand |
| 85 | MULB3 | Multiply Byte 3 Operand |
| A4 | MULW2 | Multiply Word 2 Operand |
| A5 | MULW3 | Multiply Word 3 Operand |
| C4 | MULL2 | Multiply Long 2 Operand |
| C5 | MULL3 | Multiply Long 3 Operand |

### Description

In 2 operand format, the product operand is multiplied by the multiplier operand, and the product operand is replaced by the low half of the double-length result. In 3 operand format, the multiplicand operand is multiplied by the multiplier operand, and the product operand is replaced by the low half of the double-length result.

#### Note

Integer overflow occurs if the high half of the double-length result is not equal to the sign extension of the low half of the double-length result.

## PUSHL

Push Long

### Format

opcode src.rl

### Condition Codes

N ← src LSS 0;  
 Z ← src EQL 0;  
 V ← 0;  
 C ← C;

### Exceptions

None.

### Opcodes

DD      PUSHL                      Push Long

### Description

The longword source operand is pushed on the stack.

#### Notes

1. PUSHL is equivalent to MOVL **src**, -(SP), but is 1 byte shorter.
2. POPL is not a VAX instruction. However, the assembler recognizes the inclusion of POPL destination in a program, for which it generates the code for MOVL (SP)+,destination.

## ROTL

Rotate Long

### Format

opcode cnt.rb, src.rl, dst.wl

### Condition Codes

N ← dst LSS 0;  
Z ← dst EQL 0;  
V ← 0;  
C ← C;

### Exceptions

None.

### Opcodes

9C ROTL Rotate Long

### Description

The source operand is rotated logically by the number of bits specified by the count operand, and the destination operand is replaced by the result. The source operand is unaffected. A positive count operand rotates to the left. A negative count operand rotates to the right. A zero count operand replaces the destination operand with the source operand.

---

## SBWC

Subtract with Carry

### Format

opcode    sub.rl, dif.ml

### Condition Codes

N    <—    dif LSS 0;  
Z    <—    dif EQL 0;  
V    <—    {integer overflow};  
C    <—    {borrow into most significant bit};

### Exceptions

integer overflow

### Opcodes

D9        SBWC                    Subtract with carry

### Description

The subtrahend operand and the contents of the condition code C-bit are subtracted from the difference operand, and the difference operand is replaced by the result.

#### Notes

1. On overflow, the difference operand is replaced by the low-order bits of the true result.
2. The two subtractions in the operation are performed simultaneously.

## SUB

Subtract

### Format

2operand: opcode sub.rx, dif.mx

3operand: opcode sub.rx, min.rx, dif.wx

### Condition Codes

N ← dif LSS 0;  
Z ← dif EQL 0;  
V ← {integer overflow};  
C ← {borrow into most significant bit};

### Exceptions

integer overflow

### Opcodes

|    |       |                         |
|----|-------|-------------------------|
| 82 | SUBB2 | Subtract Byte 2 Operand |
| 83 | SUBB3 | Subtract Byte 3 Operand |
| A2 | SUBW2 | Subtract Word 2 Operand |
| A3 | SUBW3 | Subtract Word 3 Operand |
| C2 | SUBL2 | Subtract Long 2 Operand |
| C3 | SUBL3 | Subtract Long 3 Operand |

### Description

In 2 operand format, the subtrahend operand is subtracted from the difference operand, and the difference operand is replaced by the result. In 3 operand format, the subtrahend operand is subtracted from the minuend operand, and the difference operand is replaced by the result.

#### Note

Integer overflow occurs if the input operands to the subtract are of different signs and the sign of the result is the sign of the subtrahend. On overflow, the difference operand is replaced by the low-order bits of the true result.

---

**TST**

Test

**Format**

opcode src.rx

**Condition Codes**

N ← src LSS 0;  
Z ← src EQL 0;  
V ← 0;  
C ← 0;

**Exceptions**

None.

**Opcodes**

|    |      |           |
|----|------|-----------|
| 95 | TSTB | Test Byte |
| B5 | TSTW | Test Word |
| D5 | TSTL | Test Long |

**Description**

The condition codes are modified according to the value of the source operand.

**Note**

The operand **src** is equivalent to  $CMP_X \text{ src}, S^{\#0}$ , but is 1 byte shorter.

## XOR

Exclusive OR

### Format

2operand: opcode mask.rx, dst.mx

3operand: opcode mask.rx, src.rx, dst.wx

### Condition Codes

N ← dst LSS 0;

Z ← dst EQL 0;

V ← 0;

C ← C;

### Exceptions

None.

### Opcodes

|    |       |                             |
|----|-------|-----------------------------|
| 8C | XORB2 | Exclusive OR Byte 2 Operand |
| 8D | XORB3 | Exclusive OR Byte 3 Operand |
| AC | XORW2 | Exclusive OR Word 2 Operand |
| AD | XORW3 | Exclusive OR Word 3 Operand |
| CC | XORL2 | Exclusive OR Long 2 Operand |
| CD | XORL3 | Exclusive OR Long 3 Operand |

### Description

In 2 operand format, the result of the logical XOR on the mask operand and the destination operand replaces the destination operand. In 3 operand format, the result of the logical XOR on the mask operand and the source operand replaces the destination operand.

### 9.2.2 Address Instructions

The following instructions are described in this section.

|    | Description and Opcode                                      | Number of Instructions |
|----|---|------------------------|
| 1. | Move Address<br>MOVA{B,W,L=F,Q=D=G,O=H} src.ax, dst.wl      | 5                      |
| 2. | Push Address<br>PUSHA{B,W,L=F,Q=D=G,O=H} src.ax, {-(SP).wl} | 5                      |

# VAX Instruction Set

## MOVA

---

### MOVA

Move Address

#### Format

opcode src.ax, dst.wl

#### Condition Codes

N ← dst LSS 0;  
Z ← dst EQL 0;  
V ← 0;  
C ← C;

#### Exceptions

None.

#### Opcodes

|      |       |                         |
|------|-------|-------------------------|
| 9E   | MOVAB | Move Address Byte       |
| 3E   | MOVAW | Move Address Word       |
| DE   | MOVAL | Move Address Long       |
|      | MOVAF | Move Address F_floating |
| 7E   | MOVAQ | Move Address Quad       |
|      | MOVAD | Move Address D_floating |
|      | MOVAG | Move Address G_floating |
| 7EFD | MOVAH | Move Address H_floating |
|      | MOVAO | Move Address Octa       |

#### Description

The destination operand is replaced by the source operand. The context in which the source operand is evaluated is given by the data type of the instruction. The operand whose address replaces the destination operand is not referenced.

#### Note

The access type of the source operand is address, which causes the address of the specified operand to be moved.

## PUSHA

Push Address

### Format

opcode src.ax

### Condition Codes

N ← src LSS 0;  
 Z ← src EQL 0;  
 V ← 0;  
 C ← C;

### Exceptions

None.

### Opcodes

|      |         |                          |
|------|---------|--------------------------|
| 9F   | PUSHAB  | Push Address Byte        |
| 3F   | PUSHAW  | Push Address Word        |
| DF   | PUSHAL  | Push Address Long,       |
|      | PUSHAFL | Push Address F_floating  |
| 7F   | PUSHAQ  | Push Address Quad,       |
|      | PUSHAD  | Push Address D_floating, |
|      | PUSHAG  | Push Address G_floating  |
| 7FFD | PUSHAH  | Push Address H_floating  |
|      | PUSHAO  | Push Address Octa        |

### Description

The source operand is pushed on the stack. The context in which the source operand is evaluated is given by the data type of the instruction. The operand whose address is pushed is not referenced.

#### Notes

1. PUSHAx **src** is equivalent to MOVAx **src**, -(SP), but is one byte shorter.
2. The source operand is of address access type, which causes the address of the specified operand to be pushed.

### 9.2.3 Variable-Length Bit Field Instructions

A variable-length bit field is specified by the following three operands:

1. A longword position operand.
2. A byte field size operand in the range 0 to 32; if out of this range, a reserved operand fault occurs.
3. A base address. Use the position operand to locate the bit field relative to this base address. The address is obtained from an operand of address access type. However, unlike other instances of operand specifiers of address access type, register mode can be designated in the operand specifier. In this case, the field is contained in the register *n* designated by the operand specifier (or register *n*+1 concatenated with register *n*). (See Chapter 8.) If the field is contained in a register and the size operand is not zero, the position operand must have a value in the range 0 to 31, or a reserved operand fault occurs.

Zero bytes are referenced if the field size is zero.

The following instructions are described in this section.

|    | Description and Opcode   | Number of Instructions |
|----|--|------------------------|
| 1. | Compare Field<br>CMPV pos.rl, size.rb, base.vb, {field.rv},<br>src.rl                | 1                      |
| 2. | Compare Zero-Extended Field<br>CMPZV pos.rl, size.rb, base.vb, {field.rv},<br>src.rl | 1                      |
| 3. | Extract Field<br>EXTV pos.rl, size.rb, base.vb, {field.rv},<br>dst.wl                | 1                      |
| 4. | Extract Zero-Extended Field<br>EXTZV pos.rl, size.rb, base.vb, {field.rv},<br>dst.wl | 1                      |
| 5. | Find First<br>FF{S,C} startpos.rl, size.rb, base.vb,<br>{field.rv}, findpos.wl       | 2                      |
| 6. | Insert Field<br>INSV src.rl, pos.rl, size.rb, base.vb,<br>{field.wv}                 | 1                      |

The following variable-length bit field instructions are described in Section 9.2.4:

|    | <b>Description and Opcode</b>   | <b>Number of Instructions</b> |
|----|---|-------------------------------|
| 1. | Branch on Bit<br>BB{S,C} pos.rl, base.vb, displ.bb,<br>{field.rv}                                     | 2                             |
| 2. | Branch on Bit (and modify without interlock)<br>BB{S,C}{S,C} pos.rl, base.vb, displ.bb,<br>{field.mv} | 4                             |
| 3. | Branch on Bit (and modify) Interlocked<br>BB{SS,CC}I pos.rl, base.vb, displ.bb,<br>{field.mv}         | 2                             |

## CMP

Compare Field

### Format

opcode pos.rl, size.rb, base.vb, src.rl

### Condition Codes

N ← tmp LSS src;  
Z ← tmp EQL src;  
V ← 0;  
C ← tmp LSSU src;

### Exceptions

reserved operand

### Opcodes

|    |       |                             |
|----|-------|-----------------------------|
| EC | CMPV  | Compare Field               |
| ED | CMPZV | Compare Zero-Extended Field |

### Description

The field specified by the position, size, and base operands is compared with the source operand. For CMPV, the source operand is compared with the sign-extended field. For CMPZV, the source operand is compared with the zero-extended field. The only action is to affect the condition codes.

#### Notes

1. A reserved operand fault occurs if:
  - **size** GTRU 32
  - **pos** GTRU 31, **size** NEQ 0, and the field is contained in the registers
2. On a reserved operand fault, the condition codes are UNPREDICTABLE.

---

## EXT

Extract Field

### Format

opcode pos.rl, size.rb, base.vb, dst.wl

### Condition Codes

N ← dst LSS 0;  
 Z ← dst EQL 0;  
 V ← 0;  
 C ← C;

### Exceptions

reserved operand

### Opcodes

|    |       |                             |
|----|-------|-----------------------------|
| EE | EXTV  | Extract Field               |
| EF | EXTZV | Extract Zero-Extended Field |

### Description

For EXTV, the destination operand is replaced by the sign-extended field specified by the position, size, and base operands. For EXTZV, the destination operand is replaced by the zero-extended field specified by the position, size, and base operands. If the size operand is zero, the only action is to replace the destination operand with zero and to modify the condition codes.

#### Notes

1. A reserved operand fault occurs if:
  - **size** GTRU 32
  - **pos** GTRU 31, **size** NEQ 0, and the field is contained in the registers
2. On a reserved operand fault, the destination operand is unaffected, and the condition codes are UNPREDICTABLE.

## FF

Find First

### Format

opcode    startpos.rl, size.rb, base.vb, findpos.wl

### Condition Codes

N     $\leftarrow$  0;  
Z     $\leftarrow$  {bit not found};  
V     $\leftarrow$  0;  
C     $\leftarrow$  0;

### Exceptions

reserved operand

### Opcodes

|    |     |                  |
|----|-----|------------------|
| EB | FFC | Find First Clear |
| EA | FFS | Find First Set   |

### Description

A field specified by the start position, size, and base operands is extracted. Starting at bit 0 and extending to the highest bit in the field, the field is tested for a bit in the state indicated by the instruction. If a bit in the indicated state is found, the find position operand is replaced by the position of the bit, and the Z condition code bit is cleared. If no bit in the indicated state is found, the find position operand is replaced by the position (relative to the base) of a bit one position to the left of the specified field, and the Z condition code bit is set. If the size operand is zero, the find position operand is replaced by the start position operand, and the Z condition code bit is set.

#### Notes

1. A reserved operand fault occurs if:
  - **size** GTRU 32
  - **startpos** GTRU 31, **size** NEQ 0, and the field is contained in the registers
2. On a reserved operand fault, the find position operand is unaffected, and the condition codes are UNPREDICTABLE.

---

## INSV

Insert Field

### Format

opcode    src.rl, pos.rl, size.rb, base.vb

### Condition Codes

N     $\leftarrow$     N;  
Z     $\leftarrow$     Z;  
V     $\leftarrow$     V;  
C     $\leftarrow$     C;

### Exceptions

reserved operand

### Opcodes

F0        INSV                    Insert Field

### Description

The field specified by the position, size, and base operands is replaced by bits  $size - 1 : 0$  of the source operand. If the size operand is zero, the instruction has no effect.

#### Notes

1. When executing INSV, a processor may read in the entire aligned longword or longwords that contains the field, replace the field portion of the aligned longword with the source operand, and write back the entire aligned longword. Because of this, data written to the nonfield portion of the aligned longword in memory by another processor or I/O device during the execution of INSV may be written over when the INSV is completed.
2. A reserved operand fault occurs if:
  - **size** GTRU 32
  - **pos** GTRU 31, **size** NEQ 0, and the field is contained in the registers
3. On a reserved operand fault, the field is unaffected, and the condition codes are UNPREDICTABLE.

## VAX Instruction Set INSV

### 9.2.4 Control Instructions

In most implementations of the VAX architecture, improved execution speed will result if the target of a control instruction is on an aligned longword boundary.

The following instructions are described in this section.

|    | Description and Opcode  | Number of Instructions |
|----|---|------------------------|
| 1. | Add Compare and Branch<br>ACB{B,W,L,F,D,G,H} limit.rx, add.rx,<br>index.mx, displ.bw<br>Compare is LE on positive add, GE on<br>negative add. | 7                      |
| 2. | Add One and Branch Less Than or Equal<br>AOBLEQ limit.rl, index.ml, displ.bb  | 1                      |
| 3. | Add One and Branch Less Than<br>AOBLSS limit.rl, index.ml, displ.bb   | 1                      |
| 4. | Conditional Branch  | 12                     |
|    | <b>Condition</b> <b>Name</b>  |                        |
|    | LSS                  Less Than  |                        |
|    | LEQ                  Less Than or Equal   |                        |
|    | EQL, EQLU          Equal, Equal Unsigned  |                        |
|    | NEQ, NEQU          Not Equal, Not Equal Unsigned  |                        |
|    | GEQ                  Greater Than or Equal  |                        |
|    | GTR                  Greater Than   |                        |
|    | LSSU, CS            Less Than Unsigned, Carry Set   |                        |
|    | LEQU                Less Than or Equal Unsigned   |                        |
|    | GEQU, CC           Greater Than or Equal Unsigned,<br>Carry Clear   |                        |
|    | GTRU                Greater Than Unsigned   |                        |
|    | VS                   Overflow Set   |                        |
|    | VC                   Overflow Clear   |                        |
| 5. | Branch on Bit<br>BB{S,C} pos.rl, base.vb, displ.bb,<br>{field.rv}   | 2                      |
| 6. | Branch on Bit<br>(and modify without interlock)<br>BB{S,C}{S,C} pos.rl, base.vb, displ.bb,<br>{field.mv}                                      | 4                      |
| 7. | Branch on Bit (and modify) Interlocked<br>BB{SS,CC}I pos.rl, base.vb, displ.bb,<br>{field.mv}   | 2                      |
| 8. | Branch on Low Bit<br>BLB{S,C} src.rl, displ.bb  | 2                      |
| 9. | Branch with {Byte, Word} Displacement<br>BR{B,W} displ.bx   | 2                      |

|     | Description and Opcode   | Number of Instructions |
|-----|--|------------------------|
| 10. | Branch to Subroutine with {Byte, Word}<br>Displacement BSB{B,W} displ.bx, {-(SP).wl} | 2                      |
| 11. | Case<br>CASE{B,W,L} selector.rx, base.rx,<br>limit.rx, displ.bw-list                 | 3                      |
| 12. | Jump<br>JMP dst.ab   | 1                      |
| 13. | Jump to Subroutine<br>JSB dst.ab, {-(SP).wl}   | 1                      |
| 14. | Return from Subroutine<br>RSB {(SP)+.rl}   | 1                      |
| 15. | Subtract One and Branch Greater Than<br>or Equal SOBGEQ index.ml, displ.bb           | 1                      |
| 16. | Subtract One and Branch Greater Than<br>SOBGTR index.ml, displ.bb                    | 1                      |

## ACB

Add Compare and Branch

### Format

opcode    limit.rx, add.rx, index.mx, displ.bw

### Condition Codes

N    <—    index LSS 0;  
Z    <—    index EQL 0;  
V    <—    {integer overflow};  
C    <—    C;

### Exceptions

integer overflow  
floating overflow  
floating underflow  
reserved operand

### Opcodes

|      |      |                                   |
|------|------|-----------------------------------|
| 9D   | ACBB | Add Compare and Branch Byte       |
| 3D   | ACBW | Add Compare and Branch Word       |
| F1   | ACBL | Add Compare and Branch Long       |
| 4F   | ACBF | Add Compare and Branch F_floating |
| 4FFD | ACBG | Add Compare and Branch G_floating |
| 6F   | ACBD | Add Compare and Branch D_floating |
| 6FFD | ACBH | Add Compare and Branch H_floating |

### Description

The addend operand is added to the index operand and the index operand is replaced by the result. The index operand is compared with the limit operand. If the addend operand is positive (or zero) and the comparison is less than or equal to zero, or if the addend is negative and the comparison is greater than or equal to zero, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result.

#### Notes

1. ACB efficiently implements the general FOR or DO loops in high-level languages, since the sense of the comparison between **index** and **limit** is dependent on the sign of the addend.
2. On integer overflow, the index operand is replaced by the low-order bits of the true result. Comparison and branch determination proceed normally on the updated index operand.

3. On floating underflow, if FU is clear, the index operand is replaced by zero, and comparison and branch determination proceed normally. A fault occurs if FU is set, and the index operand is unaffected.
4. On floating overflow, the instruction takes a floating overflow fault, and the index operand is unaffected.
5. On a reserved operand fault, the index operand is unaffected, and condition codes are UNPREDICTABLE.
6. Except for the circumstance described in note 5, the C-bit is unaffected.

## AOBLEQ

Add One and Branch Less Than or Equal

### Format

opcode    limit.rl, index.ml, displ.bb

### Condition Codes

N    <—    index LSS 0;  
Z    <—    index EQL 0;  
V    <—    {integer overflow};  
C    <—    C;

### Exceptions

integer overflow

### Opcodes

F3        AOBLEQ                    Add One and Branch Less Than or Equal

### Description

One is added to the index operand, and the index operand is replaced by the result. The index operand is compared with the limit operand. If the comparison is less than or equal to zero, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result.

#### Notes

1. Integer overflow occurs if the index operand before addition is the largest positive integer. On overflow, the index operand is replaced by the largest negative integer, and the branch is taken.
2. The C-bit is unaffected.

---

## AOBLSS

Add One and Branch Less Than

### Format

opcode    limit.rl, index.ml, displ.bb

### Condition Codes

N    <—    index LSS 0;  
Z    <—    index EQL 0;  
V    <—    {integer overflow};  
C    <—    C;

### Exceptions

integer overflow

### Opcodes

F2        AOBLS                    Add One and Branch Less Than

### Description

One is added to the index operand and the index operand is replaced by the result. The index operand is compared with the limit operand. If the comparison result is less than zero, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result.

#### Notes

1. Integer overflow occurs if the index operand before addition is the largest positive integer. On overflow, the index operand is replaced by the largest negative integer, and thus (unless the limit operand is the largest negative integer), the branch is taken.
2. The C-bit is unaffected.

## VAX Instruction Set

### B

---

### B

Branch on (condition)

#### Format

opcode displ.bb

#### Condition Codes

N ← N;

Z ← Z;

V ← V;

C ← C;

#### Exceptions

None.

#### Opcodes

|    |                |                |   |
|----|----------------|----------------|---|
| 14 | {N OR Z} EQL 0 | BGTR           | Branch on Greater Than (signed)                                   |
| 15 | {N OR Z} EQL 1 | BLEQ           | Branch on Less Than or Equal (signed)                             |
| 12 | Z EQL 0        | BNEQ,<br>BNEQU | Branch on Not Equal (signed)<br>Branch on Not Equal Unsigned      |
| 13 | Z EQL 1        | BEQL,<br>BEQLU | Branch on Equal (signed)<br>Branch on Equal Unsigned              |
| 18 | N EQL 0        | BGEQ           | Branch on Greater Than or Equal (signed)                          |
| 19 | N EQL 1        | BLSS           | Branch on Less Than (signed)                                      |
| 1A | {C OR Z} EQL 0 | BGTRU          | Branch on Greater Than Unsigned                                   |
| 1B | {C OR Z} EQL 1 | BLEQU          | Branch Less Than or Equal Unsigned                                |
| 1C | V EQL 0        | BVC            | Branch on Overflow Clear  |
| 1D | V EQL 1        | BVS            | Branch on Overflow Set  |
| 1E | C EQL 0        | BGEQU,<br>BCC  | Branch on Greater Than or Equal Unsigned<br>Branch on Carry Clear |
| 1F | C EQL 1        | BLSSU,<br>BCS  | Branch on Less Than Unsigned<br>Branch on Carry Set               |

## Description

The condition codes are tested. If the condition indicated by the instruction is met, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result.

### Notes

The VAX conditional branch instructions permit considerable flexibility in branching but require care in choosing the correct branch instruction. The conditional branch instructions are best seen as three overlapping groups:

#### 1. Overflow and Carry Group

|     |         |
|-----|---------|
| BVS | V EQL 1 |
| BVC | V EQL 0 |
| BCS | C EQL 1 |
| BCC | C EQL 0 |

Typically, you would use these instructions to check for overflow (when overflow traps are not enabled), for multiprecision arithmetic, and for other special purposes.

#### 2. Unsigned Group

|       |                |
|-------|----------------|
| BLSSU | C EQL 1        |
| BLEQU | {C OR Z} EQL 1 |
| BEQLU | Z EQL 1        |
| BNEQU | Z EQL 0        |
| BGEQU | C EQL 0        |
| BGTRU | {C OR Z} EQL 0 |

These instructions typically follow integer and field instructions where the operands are treated as unsigned integers, address instructions, and character string instructions.

#### 3. Signed Group

|      |                |
|------|----------------|
| BLSS | N EQL 1        |
| BLEQ | {N OR Z} EQL 1 |
| BEQL | Z EQL 1        |
| BNEQ | Z EQL 0        |
| BGEQ | N EQL 0        |
| BGTR | {N OR Z} EQL 0 |

These instructions typically follow floating-point instructions, decimal string instructions, and integer and field instructions where the operands are being treated as signed integers.

## BB

Branch on Bit

### Format

opcode pos.rl, base.vb, displ.bb

### Condition Codes

N ← N;  
Z ← Z;  
V ← V;  
C ← C;

### Exceptions

reserved operand

### Opcodes

|    |     |                     |
|----|-----|---------------------|
| E0 | BBS | Branch on Bit Set   |
| E1 | BBC | Branch on Bit Clear |

### Description

The single bit field specified by the position and base operands is tested. If it is in the test state indicated by the instruction, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result.

#### Notes

1. A reserved operand fault occurs if **pos** GTRU 31 and the bit specified is contained in a register.
2. On a reserved operand fault, the condition codes are UNPREDICTABLE.

## BB

Branch on Bit (and modify without interlock)

### Format

opcode pos.rl, base.vb, displ.bb

### Condition Codes

N ← N;  
Z ← Z;  
V ← V;  
C ← C;

### Exceptions

reserved operand

### Opcodes

|    |      |                               |
|----|------|-------------------------------|
| E2 | BBSS | Branch on Bit Set and Set     |
| E3 | BBCS | Branch on Bit Clear and Set   |
| E4 | BBSC | Branch on Bit Set and Clear   |
| E5 | BBCC | Branch on Bit Clear and Clear |

### Description

The single bit field specified by the position and base operands is tested. If it is in the test state indicated by the instruction, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result. Regardless of whether the branch is taken or not, the tested bit is put in the new state as indicated by the instruction.

#### Notes

1. A reserved operand fault occurs if **pos** GTRU 31 and the bit is contained in a register.
2. On a reserved operand fault, the field is unaffected, and the condition codes are UNPREDICTABLE.
3. The modification of the bit is not an interlocked operation. See BBSSI and BBCCI for interlocking instructions.

## BB

Branch on Bit Interlocked

### Format

opcode    pos.rl, base.vb, displ.bb

### Condition Codes

N    <—    N;  
Z    <—    Z;  
V    <—    V;  
C    <—    C;

### Exceptions

reserved operand

### Opcodes

|    |       |   |
|----|-------|---|
| E6 | BBSSI | Branch on Bit Set and Set Interlocked     |
| E7 | BBCCI | Branch on Bit Clear and Clear Interlocked |

### Description

The single bit field specified by the position and base operands is tested. If it is in the test state indicated by the instruction, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result. Regardless of whether the branch is taken, the tested bit is put in the new state as indicated by the instruction. If the bit is contained in memory, the reading of the state of the bit and the setting of the bit to the new state is an interlocked operation. No other processor or I/O device can do an interlocked access on this bit during the interlocked operation.

#### Notes

1. A reserved operand fault occurs if **pos** GTRU 31 and the specified bit is contained in a register.
2. On a reserved operand fault, the field is unaffected, and the condition codes are UNPREDICTABLE.
3. Except for memory interlocking, BBSSI is equivalent to BBSS, and BBCCI is equivalent to BBCC.
4. This instruction is designed to modify interlocks with other processors or devices. For example, to implement “busy waiting”:

1\$:    BBSSI    bit,base,1\$

---

## BLB

Branch on Low Bit

### Format

opcode src.rl, displ.bb

### Condition Codes

N ← N;

Z ← Z;

V ← V;

C ← C;

### Exceptions

None.

### Opcodes

|    |      |                         |
|----|------|-------------------------|
| E8 | BLBS | Branch on Low Bit Set   |
| E9 | BLBC | Branch on Low Bit Clear |

### Description

The low bit (bit 0) of the source operand is tested. If it is equal to the test state indicated by the instruction, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result.

# VAX Instruction Set

## BR

---

## BR

Branch

### Format

opcode    displ.bx

### Condition Codes

N     $\leftarrow$     N;

Z     $\leftarrow$     Z;

V     $\leftarrow$     V;

C     $\leftarrow$     C;

### Exceptions

None.

### Opcodes

|    |     |                               |
|----|-----|-------------------------------|
| 11 | BRB | Branch with Byte Displacement |
| 31 | BRW | Branch with Word Displacement |

### Description

The sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result.

---

## BSB

Branch to Subroutine

### Format

opcode    displ.bx

### Condition Codes

N    ←  N;  
Z    ←  Z;  
V    ←  V;  
C    ←  C;

### Exceptions

None.

### Opcodes

|    |      |   |
|----|------|---|
| 10 | BSBB | Branch to Subroutine with Byte Displacement |
| 30 | BSBW | Branch to Subroutine with Word Displacement |

### Description

The program counter (PC) is pushed on the stack as a longword. The sign-extended branch displacement is added to the PC, and the PC is replaced by the result.

## CASE

Case

### Format

opcode    selector.rx, base.rx, limit.rx,  
          displ[0].bw,  
          ...,  
          displ[limit].bw

### Condition Codes

N    <—    tmp LSS limit;  
Z    <—    tmp EQL limit;  
V    <—    0;  
C    <—    tmp LSSU limit;

### Exceptions

None.

### Opcodes

|    |       |           |
|----|-------|-----------|
| 8F | CASEB | Case Byte |
| AF | CASEW | Case Word |
| CF | CASEL | Case Long |

### Description

The base operand is subtracted from the selector operand, and the result replaces a temporary operand. The temporary operand is compared with the limit operand; if it is less than or equal unsigned, a branch displacement selected by the temporary value is added to the program counter (PC), and the PC is replaced by the result. Otherwise, twice the sum of the limit operand and 1 is added to the PC, and the PC is replaced by the result. This operation causes the PC to be moved past the array of branch displacements. Regardless of the branch taken, the condition codes are modified as a result of the comparison of the temporary operand with the limit operand.

#### Notes

1. After operand evaluation, the PC points at **displ**[0], not to the next instruction. The branch displacements are relative to the address of **displ**[0].
2. The selector and base operands can both be considered as either signed or unsigned integers.

In the following example, the CASEB instruction selects one of eight displacements immediately following the instruction. The example is for illustration only. An actual instruction would use run-time variables instead of the assembly-time static values shown. Also, in an actual instruction, the displacements selected by the CASEB instruction would be branches to various routines.

```

.PSECT CODE, PIC, SHR, WRT, EXE, LONG
TABIND: .WORD 4
        .ENTRY START, ^M<>
        CLRW R4
        CLRW R5
        MOVW #0, R4
        MOVW #7, R5
        CASEB TABIND, R4, R5
TAB:    .WORD 1$-TAB
        .WORD 2$-TAB
        .WORD 3$-TAB
        .WORD 4$-TAB
        .WORD 5$-TAB
        .WORD 6$-TAB
        .WORD 7$-TAB
        BRB 9$
1$:    .ASCII /AT 1/
2$:    .ASCII /AT 2/
3$:    .ASCII /AT 3/
4$:    .ASCII /AT 4/
5$:    .ASCII /AT 5/
6$:    .ASCII /AT 6/
7$:    .ASCII /AT 7/
8$:    .ASCII /AT 8/
9$:    $EXIT_S
        .END START

```

The objective of the CASE instruction is to transfer control to one of many possible locations depending on the value of “selector,” or TABIND, as shown in the example. These locations are labeled in the example from 1\$: to 8\$:.

In the example, the table contains eight branch displacements. In all cases, the limit operand (here shown as R5, which contains a 7) is one less than the number of displacements (8) in the table. The base operand (here shown as R4, which contains a zero) is the lowest permissible value for TABIND.

The CASE instruction subtracts base (contents of R4, a zero) from the value of TABIND to produce a zero-origin index into the table. The limit (contents of R5, a 7) is compared with this index to ensure that the table limit is not exceeded.

After operand evaluation, the program counter (PC) points to TAB:. The locations to which branching occurs are represented in the table as displacements. The displacement in the table selected by TABIND is added to the PC to form a destination address. The destination selected in the example is at location 5\$:.. In practical usage, this location would contain a branch to a specific routine.

# VAX Instruction Set

## JMP

---

### JMP

Jump

#### Format

opcode    dst.ab

#### Condition Codes

N     $\leftarrow$     N;

Z     $\leftarrow$     Z;

V     $\leftarrow$     V;

C     $\leftarrow$     C;

#### Exceptions

None.

#### Opcodes

17        JMP                    Jump

#### Description

The program counter (PC) is replaced by the destination operand.

## JSB

Jump to Subroutine

### Format

opcode    dst.ab

### Condition Codes

N    <—    N;

Z    <—    Z;

V    <—    V;

C    <—    C;

### Exceptions

None.

### Opcodes

|    |     |                    |
|----|-----|--------------------|
| 16 | JSB | Jump to Subroutine |
|----|-----|--------------------|

### Description

The program counter (PC) is pushed onto the stack as a longword. The PC is replaced by the destination operand.

#### Note

Because the operand specifier conventions cause the evaluation of the destination operand before saving the PC, you can use JSB for coroutine calls with the stack used for linkage. The form of this call is:

JSB @(SP)+

## RSB

Return from Subroutine

### Format

opcode

### Condition Codes

N ← N;

Z ← Z;

V ← V;

C ← C;

### Exceptions

None.

### Opcodes

|    |     |                        |
|----|-----|------------------------|
| 05 | RSB | Return from Subroutine |
|----|-----|------------------------|

### Description

The program counter (PC) is replaced by a longword popped from the stack.

#### Notes

1. Use RSB to return from subroutines called by the BSBB, BSBW, and JSB instructions.
2. RSB is equivalent to JMP @(SP)+, but is 1 byte shorter.

---

**SOBGEQ**

Subtract One and Branch Greater Than or Equal

**Format**

opcode    index.ml, displ.bb

**Condition Codes**

N     $\leftarrow$     index LSS 0;  
Z     $\leftarrow$     index EQL 0;  
V     $\leftarrow$     {integer overflow};  
C     $\leftarrow$     C;

**Exceptions**

integer overflow

**Opcodes**

|    |        |   |
|----|--------|---|
| F4 | SOBGEQ | Subtract One and Branch Greater Than or Equal |
|----|--------|---|

**Description**

One is subtracted from the index operand, and the index operand is replaced by the result. If the index operand is greater than or equal to zero, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result.

**Notes**

1. Integer overflow occurs if the index operand before subtraction is the largest negative integer. On overflow, the index operand is replaced by the largest positive integer; therefore, the branch is taken.
2. The C-bit is unaffected.

## SOBGTR

Subtract One and Branch Greater Than

### Format

opcode    index.ml, displ.bb

### Condition Codes

N    <—    index LSS 0;  
Z    <—    index EQL 0;  
V    <—    {integer overflow};  
C    <—    C;

### Exceptions

integer overflow

### Opcodes

F5        SOBGTR                    Subtract One and Branch Greater Than

### Description

One is subtracted from the index operand, and the index operand is replaced by the result. If the index operand is greater than zero, the sign-extended branch displacement is added to the program counter (PC), and the PC is replaced by the result.

#### Notes

1. Integer overflow occurs if the index operand before subtraction is the largest negative integer. On overflow, the index operand is replaced by the largest positive integer, and thus, the branch is taken.
2. The C-bit is unaffected.

### 9.2.5 Procedure Call Instructions

The following three instructions implement a standard procedure calling interface:

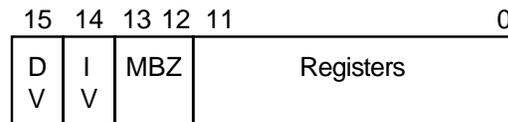
- CALLG
- CALLS
- RET

CALLG and CALLS call the procedure. The RETURN instruction returns from the procedure. Refer to the *OpenVMS Programming Concepts Manual* for the procedure calling standard.

The CALLG instruction calls a procedure with the argument list in an arbitrary location.

The CALLS instruction calls a procedure with the argument list on the stack. Upon return after a CALLS instruction, this list is automatically removed from the stack. Both call instructions specify the address of the entry point of the procedure being called. The entry point is assumed to consist of a word called the *entry mask* followed by the procedure's instructions. The procedure terminates by executing a RET instruction.

The entry mask specifies the register use and overflow enables of the subprocedure.



ZK-1162A-GE

At the occurrence of one of the call instructions, the stack is aligned to a longword boundary, and the trap enables in the processor status longword (PSW) are set to a known state to ensure consistent behavior of the called procedure. Integer overflow enable and decimal overflow enable are affected according to bits 14 and 15 of the entry mask, respectively. Floating underflow enable is cleared. Registers R11 to R0, specified by bits 11 to 0, respectively, are saved on the stack and are restored by the RET instruction. In addition, the program counter (PC), stack pointer (SP), frame pointer (FP), and argument pointer (AP) are always preserved by the CALL instructions and restored by the RET instruction.

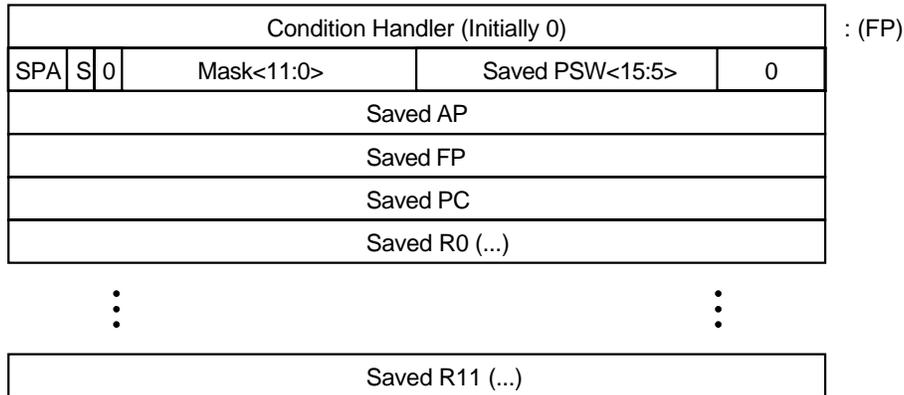
All external procedure calls generated by standard Compaq language processors and all intermodule calls to major VAX software subsystems comply with the procedure calling software standard (see the VAX Procedure Calling and Condition Handling Standard in the *OpenVMS Programming Concepts Manual*). The procedure calling standard requires that all registers in the range R2 to R11 used in the procedure must appear in the mask. R0 and R1 are not preserved by any called procedure that complies with the procedure calling standard.

To preserve the state, the CALL instructions form a structure on the stack termed a **call frame** or **stack frame**. The call frame contains the saved registers, the saved PSW, the register save mask, and several control bits. The frame also includes a longword that the CALL instructions clear. The system uses this longword to implement the OpenVMS condition handling facility (see the VAX Procedure Calling and Condition Handling Standard in the *OpenVMS Programming Interfaces: Calling a System Routine*). At the end of execution of

## VAX Instruction Set SOBGTR

the CALL instruction, the frame pointer (FP) contains the address of the stack frame. The RET instruction uses the contents of FP to find the stack frame and the restore state. The condition handling facility assumes that FP always points to the stack frame.

The stack frame has the following format:



(0 to 3 bytes specified by SPA, Stack Pointer Alignment)

S = set if CALLS; clear if CALLG.

ZK-1163A-GE

Note that the saved condition codes and the saved trace enable (PSW<T>) are cleared.

The contents of the frame PSW<3:0> at the time RET is executed will become the condition codes resulting from the execution of the procedure. Similarly, the content of the frame PSW<4> at the time the RET is executed will become the PSW<T> bit.

The following instructions are described in this section.

|    | Description and Opcode   | Number of Instructions |
|----|--|------------------------|
| 1. | Call Procedure with General Argument List<br>CALLG arglist.ab, dst.ab, {(SP).w*} | 1                      |
| 2. | Call Procedure with Stack Argument List<br>CALLS numarg.rl, dst.ab, {(SP).w*}    | 1                      |
| 3. | Return from Procedure<br>RET {(SP)+.r*}  | 1                      |

## CALLG

Call Procedure with General Argument List

### Format

opcode arglist.ab, dst.ab

### Condition Codes

N ← 0;  
Z ← 0;  
V ← 0;  
C ← 0;

### Exceptions

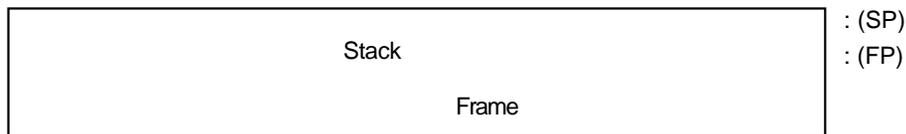
reserved operand

### Opcodes

FA CALLG Call Procedure with General Argument List

### Description

The stack pointer (SP) is saved in a temporary register. Bits 1:0 are replaced by zero, so that the stack is longword aligned. The procedure entry mask is scanned from bit 11 to bit 0, and the contents of registers whose numbers correspond to set bits in the mask are pushed on the stack as longwords. The program counter (PC), frame pointer (FP), and argument pointer (AP) are pushed on the stack as longwords. The condition codes are cleared. A longword containing the saved low 2 bits of the SP in bits 31:30, a zero in bits 29 and 28, the low 12 bits of the procedure entry mask in bits 27:16, and the processor status word (PSW) in bits 15:0 with T cleared are pushed on the stack. A longword zero is pushed on the stack. The FP is replaced by the SP. The AP is replaced by the **arglist** operand. The trap enables in the PSW are set to a known state. Integer overflow and decimal overflow are affected according to bits 14 and 15 of the entry mask, respectively; floating underflow is cleared. The T-bit is unaffected. The PC is replaced by the sum of destination operand plus 2, which transfers control to the called procedure at the byte beyond the entry mask.



(0 to 3 bytes specified by SPA)

ZK-1164A-GE

### Notes

1. If bits 13:12 of the entry mask are not zero, a reserved operand fault occurs.
2. On a reserved operand fault, condition codes are UNPREDICTABLE.

## VAX Instruction Set

### CALLG

3. The procedure calling standard and the condition handling facility require the following register saving conventions:
  - R0 and R1 are always available for function return values and are never saved in the entry mask.
  - All registers R2 to R11 that are modified in the called procedure must be preserved in the mask.

Refer to the VAX Procedure Calling and Condition Handling Standard in the *OpenVMS Programming Concepts Manual*.

---

## CALLS

Call Procedure with Stack Argument List

### Format

opcode numarg.rl, dst.ab

### Condition Codes

N ← 0;  
Z ← 0;  
V ← 0;  
C ← 0;

### Exceptions

reserved operand

### Opcodes

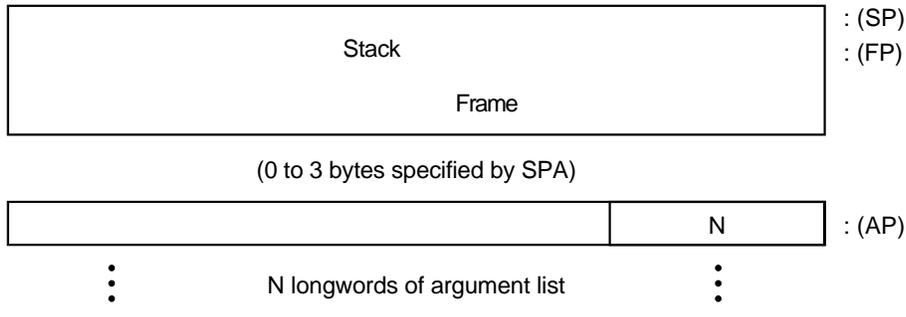
FB CALLS Call Procedure with Stack Argument List

### Description

The **numarg** operand is pushed on the stack as a longword (byte 0 contains the number of arguments; Compaq software uses the high-order 24 bits). The stack pointer (SP) is saved in a temporary register, and then bits 1:0 of the SP are replaced by zero so that the stack is longword aligned. The procedure entry mask is scanned from bit 11 to bit 0, and the contents of registers whose numbers correspond to set bits in the mask are pushed on the stack. The program counter (PC), frame pointer (FP), and argument pointer (AP) are pushed on the stack as longwords. The condition codes are cleared. A longword containing the saved low 2 bits of the SP in bits 31:30, a 1 in bit 29, a zero in bit 28, the low 12 bits of the procedure entry mask in bits 27:16, and the processor status word (PSW) in bits 15:0 with T cleared is pushed on the stack. A longword zero is pushed on the stack. The FP is replaced by the SP. The AP is set to the value of the stack pointer after the **numarg** operand was pushed on the stack. The trap enables in the PSW are set to a known state. Integer overflow and decimal overflow are affected according to bits 14 and 15 of the entry mask, respectively. Floating underflow is cleared. The T-Bit is unaffected.

## VAX Instruction Set CALLS

The PC is replaced by the sum of destination operand plus 2, which transfers control to the called procedure at the byte beyond the entry mask. The appearance of the stack after CALLS is executed is:



ZK-1165A-GE

### Notes

1. If bits 13:12 of the entry mask are not zero, a reserved operand fault occurs.
2. On a reserved operand fault, the condition codes are UNPREDICTABLE.
3. Normal use is to push the **arglist** onto the stack in reverse order prior to the CALLS. On return, the **arglist** is removed from the stack automatically.
4. The procedure calling standard and the condition handling facility require the following register saving conventions:
  - R0 and R1 are always available for function return values and are never saved in the entry mask.
  - All registers R2 to R11 that are modified in the called procedure must be preserved in the entry mask. Refer to the VAX Procedure Calling and Condition Handling Standard in the *OpenVMS Programming Concepts Manual*.

---

## RET

Return from Procedure

### Format

opcode

### Condition Codes

N ← tmp1<3>;  
 Z ← tmp1<2>;  
 V ← tmp1<1>;  
 C ← tmp1<0>;

### Exceptions

reserved operand

### Opcodes

|    |     |                       |
|----|-----|-----------------------|
| 04 | RET | Return from Procedure |
|----|-----|-----------------------|

### Description

The stack pointer (SP) is replaced by the frame pointer (FP) plus 4. A longword containing stack alignment bits in bits 31:30, a CALLS/CALLG flag in bit 29, the low 12 bits of the procedure entry mask in bits 27:16, and a saved processor status word (PSW) in bits 15:0 is popped from the stack and saved in a temporary. The program counter (PC), frame pointer (FP), and argument pointer (AP) are replaced by longwords popped from the stack. A register restore mask is formed from bits 27:16 of the temporary. Scanning from bit 0 to bit 11 of the restore mask, the contents of registers whose numbers are indicated by set bits in the mask are replaced by longwords popped from the stack. The SP is incremented by 31:30 of the temporary. The PSW is replaced by bits 15:0 of the temporary. If bit 29 in the temporary is 1 (indicating that the procedure was called by CALLS), a longword containing the number of arguments is popped from the stack. Four times the unsigned value of the low byte of this longword is added to the SP, and the SP is replaced by the result.

#### Notes

1. A reserved operand fault occurs if **tmp1**<15:8> NEQ 0.
2. On a reserved operand fault, the condition codes are UNPREDICTABLE.
3. The value of **tmp1**<28> is ignored.
4. The procedure calling standard and condition handling facility assume that procedures which return a function value or a status code do so in R0, or R0 and R1. Refer to the VAX Procedure Calling and Condition Handling Standard in the *OpenVMS Programming Concepts Manual*.

## VAX Instruction Set

### RET

#### 9.2.6 Miscellaneous Instructions

The following instructions are described in this section.

|     | Description and Opcode  | Number of Instructions |
|-----|---|------------------------|
| 1.  | Bit Clear PSW<br>BICPSW mask.rw   | 1                      |
| 2.  | Bit Set PSW<br>BISPSW mask.rw   | 1                      |
| 3.  | Breakpoint Fault<br>BPT {-(KSP).w*}   | 1                      |
| 4.  | Halt<br>HALT {-(KSP).w*}  | 1                      |
| 5.  | Index<br>INDEX subscript.rl, low.rl, high.rl,<br>size.rl, indexin.rl, indexout.wl | 1                      |
| 6.  | Move from PSL<br>MOVPSL dst.wl  | 1                      |
| 7.  | No Operation<br>NOP   | 1                      |
| 8.  | Pop Registers<br>POPR mask.rw, {(SP)+.r*}   | 1                      |
| 9.  | Push Registers<br>PUSHR mask.rw, {-(SP).w*}                                       | 1                      |
| 10. | Extended Function Call<br>XFC {unspecified operands}                              | 1                      |

---

## BICPSW

Bit Clear PSW

### Format

opcode    mask.rw

### Condition Codes

N     $\leftarrow$     N AND {NOT mask<3>};  
 Z     $\leftarrow$     Z AND {NOT mask<2>};  
 V     $\leftarrow$     V AND {NOT mask<1>};  
 C     $\leftarrow$     C AND {NOT mask<0>};

### Exceptions

reserved operand

### Opcodes

B9            BICPSW                      Bit Clear PSW

### Description

The result of the logical AND on processor status word (PSW) and the one's complement of the mask operand replaces PSW.

#### Note

A reserved operand fault occurs if **mask**<15:8> is not zero. On a reserved operand fault, the PSW is not affected.

## BISPSW

Bit Set PSW

### Format

opcode    mask.rw

### Condition Codes

N     $\leftarrow$     N OR mask<3>;

Z     $\leftarrow$     Z OR mask<2>;

V     $\leftarrow$     V OR mask<1>;

C     $\leftarrow$     C OR mask<0>;

### Exceptions

reserved operand

### Opcodes

B8            BISPSW                            Bit Set PSW

### Description

The result of the logical OR on processor status word (PSW) and the mask operand replaces PSW.

#### Note

A reserved operand fault occurs if **mask**<15:8> is not zero. On a reserved operand fault, the PSW is not affected.

## BPT

Breakpoint Fault

### Format

opcode

### Condition Codes

N ← 0; ! Condition codes cleared after BPT fault  
 Z ← 0;  
 V ← 0;  
 C ← 0;

### Exceptions

None.

### Opcodes

03      BPT                      Breakpoint Fault

### Description

To understand the operation of this instruction, refer to Appendix E. This instruction, together with the T-bit, is used to implement debugging facilities.

# VAX Instruction Set

## HALT

---

### HALT

Halt

#### Format

opcode

#### Condition Codes

N  $\leftarrow$  0; ! If privileged instruction fault,  
Z  $\leftarrow$  0; ! condition codes are cleared after  
V  $\leftarrow$  0; ! the fault. PSL saved on stack  
C  $\leftarrow$  0; ! contains condition codes prior to HALT.

N  $\leftarrow$  N; ! If processor halt  
Z  $\leftarrow$  Z;  
V  $\leftarrow$  V;  
C  $\leftarrow$  C;

#### Exceptions

privileged instruction

#### Opcodes

00      HALT                      Halt

#### Description

If the process is running in kernel mode, the processor is halted. Otherwise, a privileged instruction fault occurs. For information about privileged instruction faults, refer to Appendix E.

#### Note

This opcode is zero to trap many branches to data.

---

## INDEX

Compute Index

### Format

opcode    subscript.rl, low.rl, high.rl, size.rl, indexin.rl,  
          indexout.wl

### Condition Codes

N    <—    indexout LSS 0;  
Z    <—    indexout EQL 0;  
V    <—    0;  
C    <—    0;

### Exceptions

subscript range

### Opcodes

0A        INDEX                    index

### Description

The **indexin** operand is added to the **subscript** operand and the sum multiplied by the **size** operand. The **indexout** operand is replaced by the result. If the **subscript** operand is less than the **low** operand or greater than the **high** operand, a subscript range trap is taken.

#### Notes

1. No arithmetic exception other than subscript range can result from this instruction. Therefore, no indication is given if overflow occurs in either the add or the multiply steps. If overflow occurs on the add step, the sum is the low-order 32 bits of the true result. If overflow occurs on the multiply step, the **indexout** operand is replaced by the low-order 32 bits of the true product of the sum and the **subscript** operand. In the normal use of this instruction, overflow cannot occur without a subscript range trap occurring.
2. The index instruction is useful in index calculations for arrays of the fixed-length data types (integer and floating) and for index calculations for arrays of bit fields, character strings, and decimal strings. The **indexin** operand permits cascading INDEX instructions for multidimensional arrays. For one-dimensional bit field arrays, it also permits introduction of the constant portion of an index calculation that is not readily absorbed by address arithmetic. The following notes show some of the uses of INDEX.

## VAX Instruction Set INDEX

3. The following example shows a sequence of COBOL statements and the VAX MACRO code their compilation might generate:

```
COBOL:
01  A-ARRAY.
    02  A PIC X(10) OCCURS 15 TIMES.
01  B PIC X(10).
    MOVE A(I) TO B.
```

```
MACRO:
INDEX I, #1, #15, #10, #0, R0
MOV3 #10, A-10[R0], B.
```

4. The following example shows a sequence of PL/I statements and the VAX MACRO code their compilation might generate:

```
PL/I:
DCL A(-3:10) BIT (5);
A(I) = 1;

MACRO:
INDEX I, #-3, #10, #5, #3, R0
INSV #1, R0, #5, A ; Assumes A is byte aligned
```

5. The following example shows a sequence of FORTRAN statements and the VAX MACRO code their compilation might generate:

```
FORTRAN:
INTEGER*4 A(L1:U1, L2:U2), I, J
A(I,J) = 1

MACRO:
INDEX J, #L2, #U2, #M1, #0, R0; M1=U1-L1+1
INDEX I, #L1, #U1, #1, R0, R0;
MOVL #1, A-a[R0]; a = {{L2*M1} + L1} *4
```

## MOVPSL

Move from PSL

### Format

opcode dst.wl

### Condition Codes

N ← N;

Z ← Z;

V ← V;

C ← C;

### Exceptions

None.

### Opcodes

DC      MOVPSL                      Move from PSL

### Description

The destination operand is replaced by processor status longword (PSL).

## NOP

No Operation

### Format

opcode

### Condition Codes

N ← N;  
Z ← Z;  
V ← V;  
C ← C;

### Exceptions

None.

### Opcodes

|    |     |              |
|----|-----|--------------|
| 01 | NOP | No Operation |
|----|-----|--------------|

### Description

No operation is performed. Because the time delay caused by a NOP instruction is dependent on processor type, Compaq recommends that you do not use NOP as a means of delaying program execution. When you must have a program wait for a specified period, you should use a macro, such as the TIMEDWAIT macro, or code sequence that is not dependent on the processor's internal speed.

---

## POPR

Pop Registers

### Format

opcode    mask.rw

### Condition Codes

N     $\leftarrow$     N;

Z     $\leftarrow$     Z;

V     $\leftarrow$     V;

C     $\leftarrow$     C;

### Exceptions

None.

### Opcodes

BA    POPR                    Pop Registers

### Description

The contents of registers whose numbers correspond to set bits in the mask operand are replaced by longwords popped from the stack. R[n] is replaced if **mask**<n> is set. The mask is scanned from bit 0 to bit 14. Bit 15 is ignored.

## PUSHR

Push Registers

### Format

opcode    mask.rw

### Condition Codes

N     $\leftarrow$     N;  
Z     $\leftarrow$     Z;  
V     $\leftarrow$     V;  
C     $\leftarrow$     C;

### Exceptions

None.

### Opcodes

BB        PUSHR                    Push Registers

### Description

The contents of registers whose numbers correspond to set bits in the mask operand are pushed on the stack as longwords. R[n] is pushed if **mask**<n> is set. The mask is scanned from bit 14 to bit 0. Bit 15 is ignored.

#### Note

The order of pushing is specified so that the contents of higher-numbered registers are stored at higher memory addresses. An example of a result of this would be a double-floating datum stored in adjacent registers being stored by PUSHR in memory in the correct order.

---

## XFC

Extended Function Call

### Format

opcode

### Condition Codes

N ← 0;

Z ← 0;

V ← 0;

C ← 0;

### Exceptions

None.

### Opcodes

|    |     |                        |
|----|-----|------------------------|
| FC | XFC | Extended Function Call |
|----|-----|------------------------|

### Description

To understand the operation of this instruction, refer to Appendix E and the *VAX Architecture Reference Manual*. This instruction provides for customer-defined extensions to the instruction set.

### 9.2.7 Queue Instructions

A queue is a circular, doubly linked list. A queue entry is specified by its address. Each queue entry is linked to the next by a pair of longwords. The first longword is the forward link; it specifies the location of the succeeding entry. The second longword is the backward link; it specifies the location of the preceding entry. Because a queue contains redundant links, it is possible to create ill-formed queues. The VAX instructions produce UNPREDICTABLE results when used on ill-formed queues.

A queue is classified by the type of link that it uses. The VAX supports two distinct types of links: absolute and self-relative.

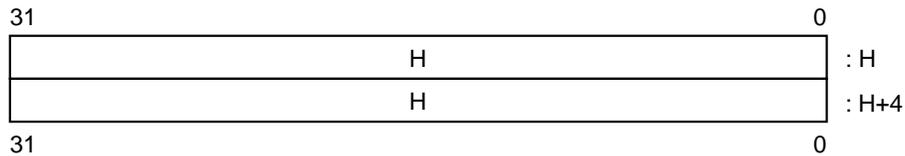
#### 9.2.7.1 Absolute Queues

Absolute queues use absolute addresses as links. Queue entries are linked by a pair of longwords. The first (lowest-addressed) longword is the forward link; it is the address of the succeeding queue entry. The second (highest-addressed) longword is the backward link; it is the address of the preceding queue entry.

A queue is specified by a queue header, which is identical to a pair of queue linkage longwords. The forward link of the header is the address of the entry called the **head** of the queue. The backward link of the header is the address of the entry termed the **tail** of the queue. The forward link of the tail points to the header.

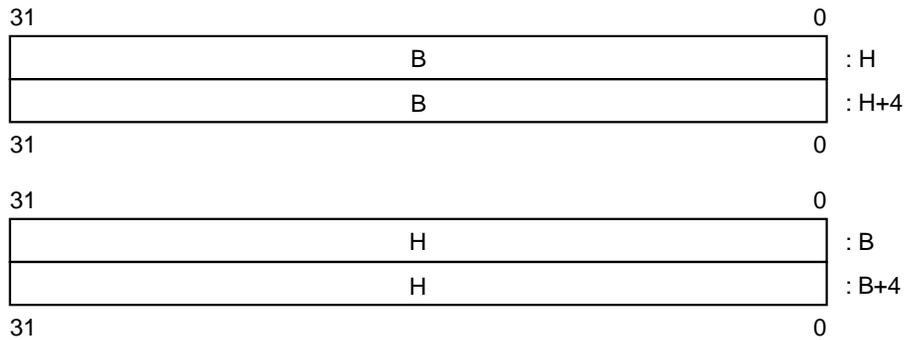
Two general operations can be performed on queues: insertion of entries and removal of entries. Generally, entries can be inserted or removed only at the head or tail of a queue. (Under certain restrictions they can be inserted or removed elsewhere; this is discussed later.)

The following text contains examples of queue operations. An empty queue is specified by its header at address H.



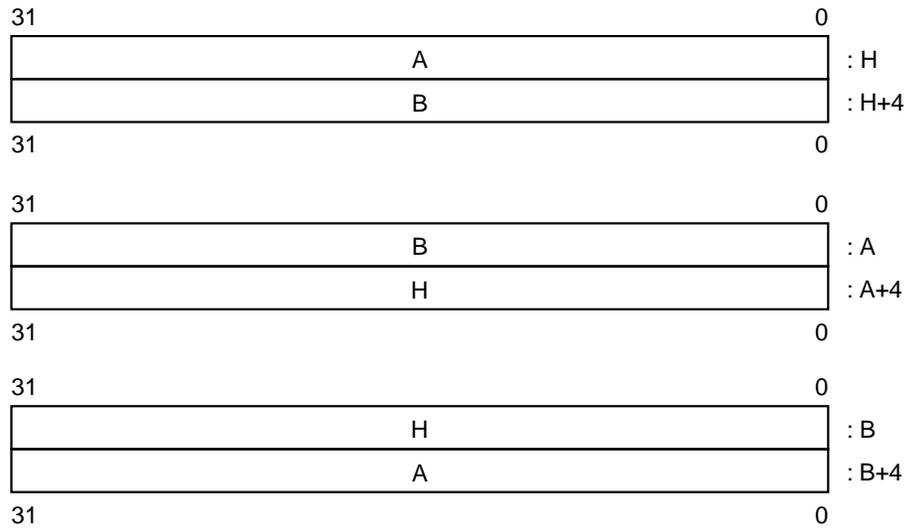
ZK-1166A-GE

If an entry at address B is inserted into an empty queue (at either the head or the tail), the queue appears as follows:



ZK-1167A-GE

If an entry at address A is inserted at the head of the queue, the queue appears as follows:

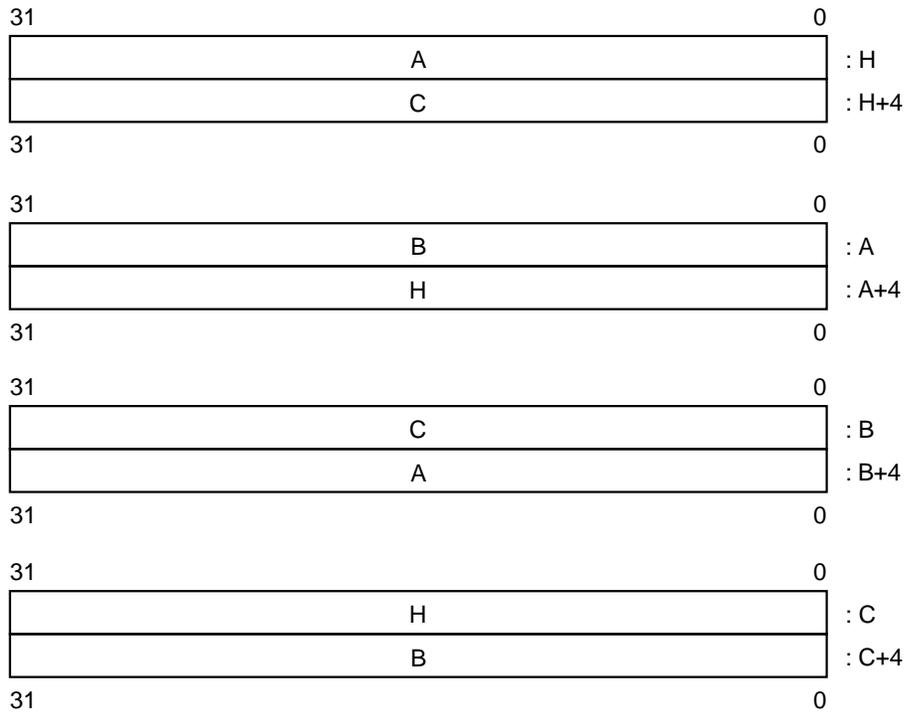


ZK-1168A-GE

# VAX Instruction Set

## XFC

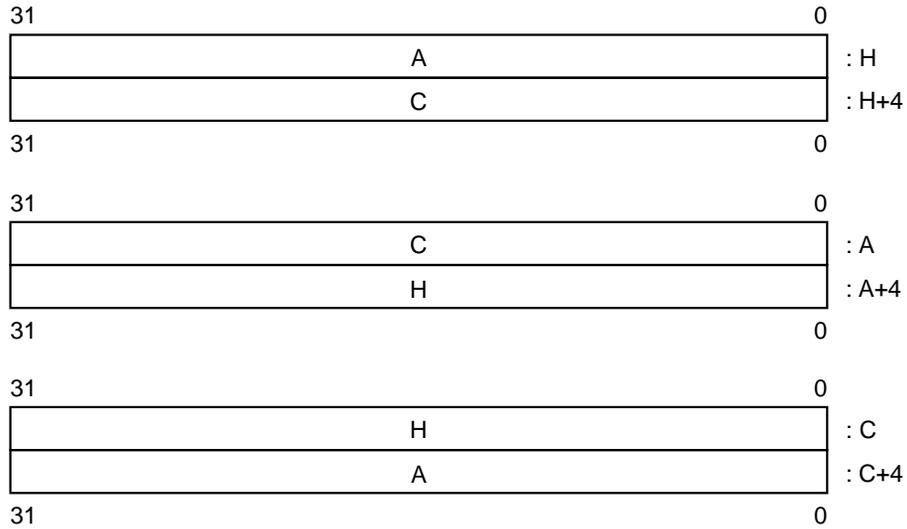
Finally, if an entry at address C is inserted at the tail, the queue appears as follows:



ZK-1169A-GE

Following the preceding steps in reverse order gives the effect of removal at the tail and removal at the head.

If more than one process can perform operations on a queue simultaneously, insertions and removals should only be done at the head or tail of the queue. If only one process (or one process at a time) can perform operations on a queue, insertions and removals can be made at other than the head or tail of the queue. In the preceding example with the queue containing entries A, B, and C, the entry at address B can be removed, giving the following:



ZK-1170A-GE

The reason for this restriction is that operations at the head or tail are always valid because the queue header is always present. Operations elsewhere in the queue depend on specific entries being present and may become invalid if another process is simultaneously performing operations on the queue.

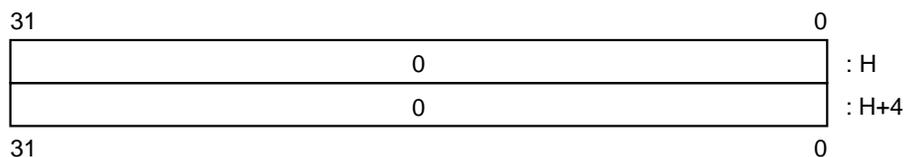
Two instructions are provided for manipulating absolute queues: `INSQUE` and `REMQUE`. `INSQUE` inserts an entry specified by an entry operand into the queue following the entry specified by the predecessor operand. `REMQUE` removes the entry specified by the entry operand. Queue entries can be on arbitrary byte boundaries. Both `INSQUE` and `REMQUE` are implemented as noninterruptible instructions.

### 9.2.7.2 Self-Relative Queues

Self-relative queues use displacements from queue entries as links. Queue entries are linked by a pair of longwords. The first (lowest addressed) longword is the forward link; it is the displacement of the succeeding queue entry from the present entry. The second (highest-addressed) longword is the backward link; it is the displacement of the preceding queue entry from the present entry.

A queue is specified by a queue header, which also consists of two longword links. The forward link of the header is the address of the entry called the *head* of the queue. The backward link of the header is the address of the entry called the *tail* of the queue. The forward link of the tail points to the header.

The following text contains examples of queue operations. An empty queue is specified by its header at address H. Because the queue is empty, the self-relative links must be zero, as shown.

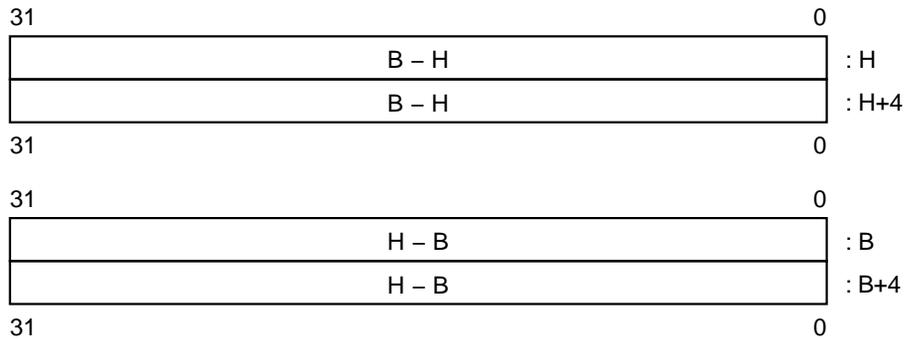


ZK-1171A-GE

# VAX Instruction Set

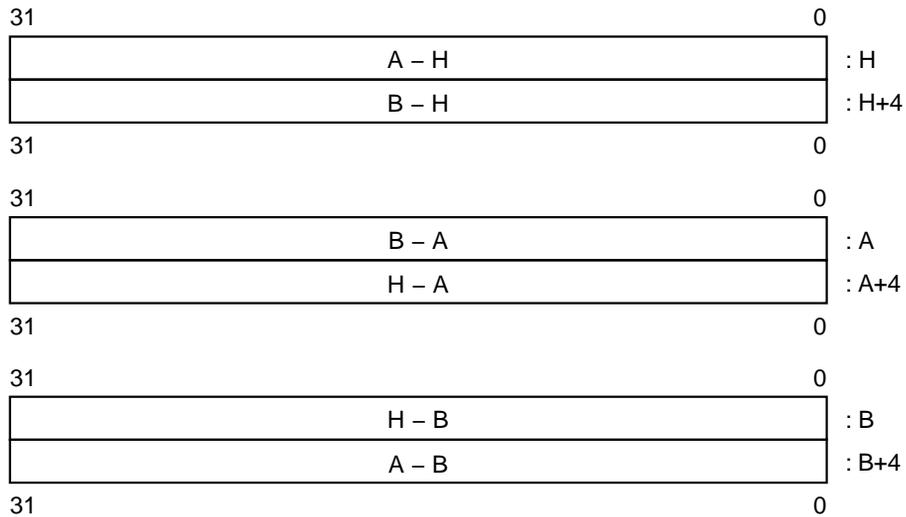
## XFC

If an entry at address B is inserted into an empty queue (at either the head or tail), the queue appears as follows:



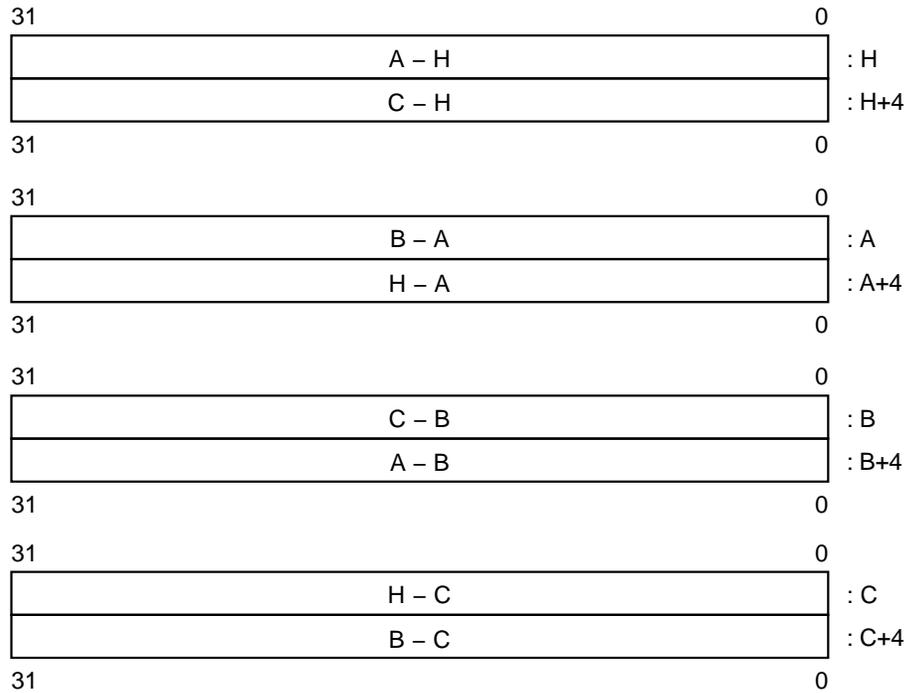
ZK-1172A-GE

If an entry at address A is inserted at the head of the queue, the queue appears as follows:



ZK-1173A-GE

Finally, if an entry at address C is inserted at the tail, the queue appears as follows:



ZK-1174A-GE

Following the previous steps in reverse order gives the effect of removal at the tail and at the head.

The following four instructions manipulate self-relative queues:

1. **INSQHI**—Insert entry into queue at head, interlocked.
2. **INSQTI**—Insert entry into queue at tail, interlocked.
3. **REMQHI**—Remove entry from queue at head, interlocked.
4. **REMQTI**—Remove entry from queue at tail, interlocked.

These operations are interlocked to allow cooperating processes in a multiprocessor system to access a shared list without additional synchronization. Queue entries must be quadword aligned. A hardware-supported interlocked memory access mechanism is used to read the queue header. Bit 0 of the queue header is used as a secondary interlock; it is set when the queue is being accessed.

If an interlocked queue instruction encounters the secondary interlock set, then, if no exception conditions exist, it terminates after setting the condition codes to indicate failure to gain access to the queue. If the secondary interlock bit is not set, then the interlocked queue instruction sets the secondary interlock bit during instruction execution and clears the secondary interlock bit at instruction completion. In this way, other interlocked queue instructions are prevented from operating on the same queue.

If an interlocked queue instruction encounters both the secondary interlock set and an exception condition resulting from instruction execution, then it is UNPREDICTABLE whether the exception occurs or the instruction terminates after setting the condition codes.

## VAX Instruction Set

### XFC

#### 9.2.7.3 Instruction Descriptions

The following instructions are described in this section:

|    | <b>Description and Opcode</b>  | <b>Number of Instructions</b> |
|----|--|-------------------------------|
| 1. | Insert Entry into Queue at Head, Interlocked<br>INSQHI entry.ab, header.aq | 1                             |
| 2. | Insert Entry into Queue at Tail, Interlocked<br>INSQTI entry.ab, header.aq | 1                             |
| 3. | Insert Entry in Queue<br>INSQUE entry.ab, pred.ab                          | 1                             |
| 4. | Remove Entry from Queue at Head, Interlocked<br>REMQHI header.aq, addr.wl  | 1                             |
| 5. | Remove Entry from Queue at Tail, Interlocked<br>REMQTI header.aq, addr.wl  | 1                             |
| 6. | Remove Entry from Queue<br>REMQUE entry.ab, addr.wl                        | 1                             |

---

## INSQHI

Insert Entry into Queue at Head, Interlocked

### Format

opcode    entry.ab, header.aq

### Condition Codes

```

if {insertion succeeded} then
begin
N ← 0;
Z ← (entry) EQL (entry+4); ! First entry in queue
V ← 0;
C ← 0;
end;
else
begin
N ← 0;
Z ← 0;
V ← 0;
C ← 1;           ! Secondary interlock failed
end;

```

### Exceptions

reserved operand

### Opcodes

5C       INSQHI                   Insert Entry into Queue at Head, Interlocked

### Description

The entry specified by the entry operand is inserted into the queue following the header. If the entry inserted was the first one in the queue, the condition code Z-bit is set; otherwise it is cleared. The insertion is a noninterruptible operation. The insertion is interlocked to prevent concurrent interlocked insertions or removals at the head or tail of the same queue by another process even in a multiprocessor environment. Before performing any part of the operation, the processor validates that the entire operation can be completed. This method ensures that if a memory management exception occurs (see Appendix E), the queue is left in a consistent state. If the instruction fails to acquire the secondary interlock, then, if no exception conditions exist, the instruction sets condition codes and terminates.

## VAX Instruction Set

### INSQHI

#### Notes

1. Because the insertion is noninterruptible, processes running in kernel mode can share queues with interrupt service routines.
2. The INSQHI, INSQTI, REMQHI, and REMQTI instructions are implemented such that cooperating software processes in a multiprocessor may access a shared list without additional synchronization.
3. To set a software interlock realized with a queue, you can use the following:

```
INSERT:
    INSQHI    ...           ; Was queue empty?
    BEQL     1$           ; Yes
    BCS      INSERT       ; Try inserting again
    CALL     WAIT(...)    ; No, wait
```

1\$:

4. During access validation, any access that cannot be completed results in a memory management exception even though the queue insertion is not started.
5. A reserved operand fault occurs if **entry** or **header** is an address that is not quadword aligned (that is,  $\langle 2:0 \rangle \text{ NEQU } 0$ ) or if **header** $\langle 2:1 \rangle$  is not zero. A reserved operand fault also occurs if **header** equals **entry**. In this case, the queue is not altered.
6. If an interlocked queue instruction encounters both the secondary interlock set and an exception condition resulting from instruction execution, then it is UNPREDICTABLE whether the exception occurs or the instruction terminates after setting the condition codes.

---

## INSQTI

Insert Entry into Queue at Tail, Interlocked

### Format

opcode    entry.ab, header.aq

### Condition Codes

```

if {insertion succeeded} then
begin
N ← 0;
Z ← (entry) EQL (entry+4); ! First entry in queue
V ← 0;
C ← 0;
end;
else
begin
N ← 0;
Z ← 0;
V ← 0;
C ← 1;           ! Secondary interlock failed
end;

```

### Exceptions

reserved operand

### Opcodes

5D      INSQTI                    Insert Entry into Queue at Tail, Interlocked

### Description

The entry specified by the entry operand is inserted into the queue preceding the header. If the entry inserted was the first one in the queue, the condition code Z-bit is set; otherwise, it is cleared. The insertion is a noninterruptible operation. The insertion is interlocked to prevent concurrent interlocked insertions or removals at the head or tail of the same queue by another process even in a multiprocessor environment. Before performing any part of the operation, the processor validates that the entire operation can be completed. This method ensures that if a memory management exception occurs (see Appendix E), queue is left in a consistent state. If the instruction fails to acquire the secondary interlock, then, if no exception conditions exist, the instruction sets condition codes and terminates.

## VAX Instruction Set

### INSQTI

#### Notes

1. Because the insertion is noninterruptible, processes running in kernel mode can share queues with interrupt service routines.
2. The INSQHI, INSQTI, REMQHI, and REMQTI instructions are implemented such that cooperating software processes in a multiprocessor may access a shared list without additional synchronization.
3. To set a software interlock realized with a queue, you can use the following:

```
INSERT:
    INSQHI    ...           ; Was queue empty?
    BEQL     1$            ; Yes
    BCS      INSERT        ; Try inserting again
    CALL     WAIT(...)     ; No, wait
```

1\$:

4. During access validation, any access that cannot be completed results in a memory management exception even though the queue insertion is not started.
5. A reserved operand fault occurs if **entry**, **header**, or (**header+4**) is an address that is not quadword aligned (that is,  $\langle 2:0 \rangle \text{ NEQU } 0$ ) or if **header** $\langle 2:1 \rangle$  is not zero. A reserved operand fault also occurs if **header** equals **entry**. In this case, the queue is not altered.
6. If the instruction encounters both the secondary interlock set and an exception condition resulting from instruction execution, then it is UNPREDICTABLE whether the exception occurs or the instruction terminates after setting the condition codes.

---

## INSQUE

Insert Entry in Queue

### Format

opcode    entry.ab, pred.ab

### Condition Codes

N    <—    (entry) LSS (entry+4);  
 Z    <—    (entry) EQL (entry+4); ! First entry in queue  
 V    <—    0;  
 C    <—    (entry) LSSU (entry+4);

### Exceptions

None.

### Opcodes

0E        INSQUE                    Insert Entry in Queue

### Description

The entry specified by the entry operand is inserted into the queue following the entry specified by the predecessor operand. If the entry inserted was the first one in the queue, the condition code Z-bit is set; otherwise it is cleared. The insertion is a noninterruptible operation. Before performing any part of the operation, the processor validates that the entire operation can be completed. This method ensures that if a memory management exception occurs (see Appendix E), the queue is left in a consistent state.

### Notes

- The following three types of insertion can be performed by appropriate choice of the predecessor operand:
  - Insert at head:  

```
INSQUE entry, h                    ; h is queue head
```
  - Insert at tail:  

```
INSQUE entry,@h+4                ; h is queue head
(Note "@" in this case only)
```
  - Insert after arbitrary predecessor:  

```
INSQUE entry,p                    ; p is predecessor
```
- Because the insertion is noninterruptible, processes running in kernel mode can share queues with interrupt service routines.
- The INSQUE and REMQUE instructions are implemented such that cooperating software processes in a single processor may access a shared list without additional synchronization, if the insertions and removals are only at the head or tail of the queue.

## VAX Instruction Set

### INSQUE

4. To set a software interlock realized with a queue, you can use the following:

```
INSQUE  ...           ; Was queue empty?
BEQL    1$           ; Yes
CALL    WAIT(...)    ; No, wait
```

1\$:

5. During access validation, any access that cannot be completed results in a memory management exception, even though the queue insertion is not started.

---

## REMQHI

Remove Entry from Queue at Head, Interlocked

### Format

opcode header.aq, addr.wl

### Condition Codes

```

if {removal succeeded} then
begin
N ← 0;
Z ← (header) EQL 0; ! Queue empty after removal
V ← {queue empty before this instruction};
C ← 0;
end;
else
begin
N ← 0;
Z ← 0;
V ← 1; ! Did not remove anything
C ← 1; ! Secondary interlock failed
end;

```

### Exceptions

reserved operand

### Opcodes

|    |        |   |
|----|--------|---|
| 5E | REMQHI | Remove Entry from Queue at Head,<br>Interlocked |
|----|--------|---|

### Description

If the secondary interlock is clear, the queue entry following the header is removed from the queue and the address operand is replaced by the address of the entry removed. If the queue was empty prior to this instruction, or if the secondary interlock failed, the condition code V-bit is set; otherwise it is cleared.

If the interlock succeeded and the queue is empty at the end of this instruction, the condition code Z-bit is set; otherwise, it is cleared. The removal is interlocked to prevent concurrent interlocked insertions or removals at the head or tail of the same queue by another process even in a multiprocessor environment. The removal is a noninterruptible operation. Before performing any part of the operation, the processor validates that the entire operation can be completed. This ensures that if a memory management exception occurs (see Appendix E), the queue is left in a consistent state. If the instruction fails to acquire the secondary interlock, then, if no exception conditions exist, the instruction sets condition codes and terminates.

## VAX Instruction Set

### REMQHI

#### Notes

1. Because the removal is noninterruptible, processes running in kernel mode can share queues with interrupt service routines.
2. The INSQHI, INSQTI, REMQHI, and REMQTI instructions are implemented so that cooperating software processes in a multiprocessor may access a shared list without additional synchronization.
3. To release a software interlock realized with a queue, you can use the following:

```
1$:  REMQHI  ...           ; Removed last?
      BEQL   2$           ; Yes
      BCS   1$           ; Try removing again
      CALL  ACTIVATE(...) ; Activate other waiters
```

2\$:

4. To remove entries until the queue is empty, you can use the following:

```
1$:  REMQHI  ...           ; Anything removed?
      BVS   2$           ; No
      .
      process removed entry
      .
      BR    1$           ;
      .
2$:  BCS   1$           ; Try removing again
      queue empty
```

5. During access validation, any access that cannot be completed results in a memory management exception, even though the queue removal is not started.
6. A reserved operand fault occurs if **header** or (**header** + (**header**)) is an address that is not quadword aligned (that is,  $\langle 2:0 \rangle \text{ NEQU } 0$ ) or if (**header**) $\langle 2:1 \rangle$  is not zero. A reserved operand fault also occurs if the header address operand equals the address of the **addr** operand. In this case, the queue is not altered.
7. If the instruction encounters both the secondary interlock set and an exception condition resulting from instruction execution, then it is UNPREDICTABLE whether the exception occurs or the instruction terminates after setting the condition codes.

---

## REMQTI

Remove Entry from Queue at Tail, Interlocked

### Format

opcode header.aq, addr.wl

### Condition Codes

```

if {removal succeeded} then
begin
N ← 0;
Z ← (header + 4) EQL 0; ! Queue empty after removal
V ← {queue empty before this instruction};
C ← 0;
end;
else
begin
N ← 0;
Z ← 0;
V ← 1; ! Did not remove anything
C ← 1; ! Secondary interlock failed
end;

```

### Exceptions

reserved operand

### Opcodes

|    |        |  |
|----|--------|--|
| 5F | REMQTI | Remove Entry from Queue at Tail, Interlocked |
|----|--------|--|

### Description

If the secondary interlock is clear, the queue entry preceding the header is removed from the queue and the address operand is replaced by the address of the entry removed. If the queue was empty prior to this instruction, or if the secondary interlock failed, the condition code V-bit is set; otherwise it is cleared.

If the interlock succeeded and the queue is empty at the end of this instruction, the condition code Z-bit is set; otherwise it is cleared. The removal is interlocked to prevent concurrent interlocked insertions or removals at the head or tail of the same queue by another process, even in a multiprocessor environment. The removal is a noninterruptible operation. Before performing any part of the operation, the processor validates that the entire operation can be completed. This ensures that if a memory management exception occurs (see Appendix E), the queue is left in a consistent state. If the instruction fails to acquire the secondary interlock, then, if no exception conditions exist, the instruction sets condition codes and terminates.

## VAX Instruction Set

### REMQTI

#### Notes

1. Because the removal is noninterruptible, processes running in kernel mode can share queues with interrupt service routines.
2. The INSQHI, INSQTI, REMQHI, and REMQTI instructions are implemented to allow cooperating software processes in a multiprocessor system to access a shared list without additional synchronization.
3. To release a software interlock realized with a queue, you can use the following:

```
1$:  REMQTI  ...           ; Removed last?
      BEQL   2$           ; Yes
      BCS   1$           ; Try removing again
      CALL  ACTIVATE(...) ; Activate other waiters
```

```
2$:
```

4. To remove entries until the queue is empty, you can use the following:

```
1$:  REMQTI  ...           ; Anything removed?
      BVS   2$           ; No
      .
      process removed entry
      .
      BR    1$           ;
      .
2$:  BCS   1$           ; Try removing again
      queue empty
```

5. During access validation, any access that cannot be completed results in a memory management exception, even though the queue removal is not started.
6. A reserved operand fault occurs if **header**, (**header** + 4), or (**header** + (**header** + 4)+4) is an address that is not quadword aligned (that is,  $\langle 2:0 \rangle$  NEQU 0), or if  $\langle 2:1 \rangle$  is not zero. A reserved operand fault also occurs if the header address operand equals the address of the **addr** operand. In this case, the queue is not altered.
7. If the instruction encounters both the secondary interlock set and an exception condition resulting from instruction execution, then it is UNPREDICTABLE whether the exception occurs or the instruction terminates after setting the condition codes.

## REMQUE

Remove Entry from Queue

### Format

opcode    entry.ab,addr.wl

### Condition Codes

N    <—    (entry) LSS (entry+4);  
 Z    <—    (entry) EQL (entry+4); ! Queue empty  
 V    <—    (entry) EQL (entry+4); ! No entry to remove  
 C    <—    (entry) LSSU (entry+4);

### Exceptions

None.

### Opcodes

0F        REMQUE                    Remove Entry from Queue

### Description

The queue entry specified by the entry operand is removed from the queue. The address operand is replaced by the address of the entry removed. If there was no entry in the queue to be removed, the condition code V-bit is set; otherwise it is cleared. If the queue is empty at the end of this instruction, the condition code Z-bit is set; otherwise it is cleared. The removal is a noninterruptible operation. Before performing any part of the operation, the processor validates that the entire operation can be completed. This ensures that if a memory management exception occurs (see Appendix E), the queue is left in a consistent state.

### Notes

1. The following three types of removal can be performed by suitable choice of entry operand:
  - Remove at head:  
    REMQUE @h,addr               ; h is queue header
  - Remove at tail:  
    REMQUE @h+4,addr             ; h is queue header
  - Remove arbitrary entry:  
    REMQUE entry,addr
2. Because the removal is noninterruptible, processes running in kernel mode can share queues with interrupt service routines.
3. The INSQUE and REMQUE instructions are implemented so that cooperating software processes in a single processor may access a shared list without additional synchronization, if the insertions and removals are only at the head or tail of the queue.

## VAX Instruction Set

### REMQUE

4. To release a software interlock realized with a queue, you can use the following:

```
REMQUE ...           ; Queue empty?
BEQL 1$              ; Yes
CALL  ACTIVATE(...) ; Activate other waiters
```

1\$:

5. To remove entries until the queue is empty, you can use the following:

```
1$:  REMQUE ...           ; Anything removed?
      BVS  EMPTY         ; No
      .
      .
      .
      BR  1$
```

6. During access validation, any access that cannot be completed results in a memory management exception, even though the queue removal is not started.

## 9.2.8 Floating-Point Instructions

Floating-point instructions operate on the following four data types:

- F\_floating, standard on all VAX processors
- D\_floating, standard on all VAX processors
- G\_floating, optional on the VAX-11/780 and the VAX-11/750, and standard on the VAX-11/730
- H\_floating, optional on the VAX-11/780 and the VAX-11/750, and standard on the VAX-11/730

To be consistent with the floating-point instruction set, which faults on reserved operands (see Chapter 8), software-implemented floating-point functions (for example, the absolute function) should verify that no input operands are reserved. An easy way to do this is a floating move or test of the input operands.

To make high-speed, floating-point operations easier, restrictions are placed on the addressing mode combinations usable within a single floating-point instruction. These combinations involve the logically inconsistent simultaneous use of a value as both a floating-point operand and an address.

If, within the same instruction, you use the contents of register Rn as both a part of a floating-point input operand (an .rf, .rd, .rg, .rh, .mf, .md, .mg, or .mh operand) and as an address in an addressing mode that modifies Rn (autoincrement, autodecrement, or autoincrement deferred), the value of the floating-point operand is UNPREDICTABLE.

### 9.2.8.1 Introduction

Mathematically, a floating-point number may be defined as having the following form:

$$(+or-)(2^{**K}) * f$$

where **K** is an integer and **f** is a nonnegative fraction. For a nonvanishing number, **K** and **f** are uniquely determined by imposing the following condition:

$$1/2 \text{ LEQ } f \text{ LSS } 1.$$

The fractional factor, **f**, of the number is then said to be **binary normalized**. For the number 0, **f** must be assigned the value zero, and the value of **K** is indeterminate.

VAX derives these floating-point data formats from this mathematical representation for floating-point numbers. Four types of floating-point data are provided: the two standard PDP-11 formats (F\_floating and D\_floating), and two extended-range formats (G\_floating and H\_floating). Single-precision, or floating, data is 32 bits long. Double-precision, or D\_floating, data is 64 bits long. Extended-range double-precision, or G\_floating, data is 64 bits long. Extended-range quadruple-precision, or H\_floating, data is 128 bits long. Use sign magnitude notation as follows:

1. Nonzero floating-point numbers:

The most significant bit of the floating-point data is the sign bit: 0 for positive and 1 for negative.

## VAX Instruction Set

### REMQUE

The fractional factor **f** is assumed normalized, so that its most significant bit must be 1. This 1 is the “hidden” bit: it is not stored in the data word, but the hardware restores it before carrying out arithmetic operations. The **F\_floating** and **D\_floating** data types use 23 and 55 bits, respectively, for **f**, which, with the hidden bit, imply effective significance of 24 bits and 56 bits for arithmetic operations. The extended-range (**G\_floating** and **H\_floating**) data types use 52 and 112 bits, respectively, for **f**, which, with the hidden bit, imply effective significance of 53 and 113 bits for arithmetic operations.

In the **F\_floating** and **D\_floating** data types, 8 bits are reserved for the storage of the exponent **K** in excess 128 notation. Thus, exponents from -128 to +127 could be represented, in biased form, by 0 to 255. For reasons given later, a biased exponent of zero (the true exponent of -128) is reserved for floating-point zero. Thus, for **F\_floating** and **D\_floating** data types, exponents are restricted to the range -127 to +127 inclusive or, in excess 128 notation, 1 to 255.

In the **G\_floating** data type, 11 bits are reserved for the storage of the exponent in excess 1024 notation. In the **H\_floating** data type, 15 bits are reserved for the storage of the exponent in excess 16,384 notation. A biased exponent of zero is reserved for floating-point zero. Thus, exponents are restricted to -1023 to +1023 inclusive (in excess notation, 1 to 2047), and -16,383 to +16,383 inclusive (in excess notation, 1 to 32,767) for **G\_floating** and **H\_floating** data types, respectively.

#### 2. Floating-point 0:

Because of the hidden bit, the fractional factor is not available to distinguish between zero and nonzero numbers whose fractional factor is exactly 1/2. Therefore, the VAX reserves a sign-exponent field of zero for this purpose. Any positive floating-point number with a biased exponent of zero is treated as if it were an exact zero by the floating-point instruction set. In particular, a floating-point operand whose bits are all zeros is treated as zero, and this is the format generated by all floating-point instructions for which the result is zero.

#### 3. The reserved operands:

A reserved operand is defined to be any bit pattern with a sign bit of 1 and a biased exponent of zero. On the VAX, all floating-point instructions generate a fault if a reserved operand is encountered. A reserved operand is never generated as a result of a floating-point instruction. Scalar floating-point instructions never generate a reserved operand. However, vector floating-point instructions can generate reserved operands.

### 9.2.8.2 Overview of the Instruction Set

The VAX has the standard arithmetic operations **ADD**, **SUB**, **MUL**, and **DIV** implemented for all four floating-point data types. The results of these operations are always rounded, as described in Section 9.2.8.3. In addition, VAX has two composite operations, **EMOD** and **POLY**, also implemented for all four floating-point data types. **EMOD** generates a product of two operands and then separates the product into its integer and fractional terms. **POLY** evaluates a polynomial, given the degree, the argument, and a pointer to a table of coefficients. Details on the operation of **EMOD** and **POLY** are given in their respective descriptions. All of these instructions are subject to the rounding errors associated with floating-point operations, as well as to exponent overflow and underflow. Accuracy is discussed in Section 9.2.8.3. Exceptions are discussed in Appendix E.

The VAX architecture also has a complete set of instructions for conversion from integer arithmetic types (byte, word, longword) to all floating types (F\_floating, D\_floating, G\_floating, H\_floating), and vice versa. The VAX architecture also has a set of instructions for conversion between all of the floating types except between D\_floating and G\_floating. Many of these instructions are exact, in the sense defined in Section 9.2.8.3. However, a few may generate rounding error, floating overflow, or floating underflow, or induce integer overflow. Details are given in the description of the CVT instructions.

The following move-type instructions are always exact: MOV, NEG, CLR, CMP, and TST. The ACB (Add Compare and Branch) instruction is subject to rounding errors, overflow, and underflow.

All of the floating-point instructions on the VAX architecture fault if they encounter a reserved operand. Floating-point instructions also fault on the occurrence of floating overflow or divide by zero, and the condition codes are UNPREDICTABLE. The FU bit in the processor status word (PSW) is available to enable or disable an exception on underflow. If the FU bit is clear, no exception occurs on underflow and zero is returned as the result. If the FU bit is set, a fault occurs on underflow. Further details on the actions taken if any of these exceptions occurs are included in the descriptions of the instructions and discussed in Appendix E.

### 9.2.8.3 Accuracy

This section discusses general comments on the accuracy of the VAX floating-point instruction set. The descriptions of the individual instructions may include additional details on their accuracy.

An instruction is defined to be exact if its result, extended on the right by an infinite sequence of zeros, is identical to that of an infinite precision calculation involving the same operands. The prior accuracy of the operands is ignored. For all arithmetic operations except DIV, a zero operand implies that the instruction is exact. The instruction is exact for DIV if the 0 operand is the dividend. If the 0 operand is the divisor, division is undefined and the instruction faults.

For nonzero floating-point operands, the fractional factor is binary normalized with 24 or 56 bits for single-precision (F\_floating) or double-precision (D\_floating), respectively; and 53 or 113 bits for extended-range double-precision (G\_floating), and extended-range quadruple-precision (H\_floating), respectively. The ADD, SUB, MUL, and DIV instructions require an overflow bit (on the left) and two guard bits (on the right) to guarantee the return of a rounded result identical to the corresponding infinite precision operation rounded to the specified word length. With these two guard bits, a rounded result has an error bound of 1/2 LSB (least significant bit).

Note that an arithmetic result is exact if no nonzero bits are lost in chopping the infinite precision result to the data length to be stored. Chopping is defined to mean that the 24 (F\_floating), 56 (D\_floating), 53 (G\_floating), or 113 (H\_floating) high-order bits of the normalized fractional factor of a result are stored; the rest of the bits are discarded. The first bit lost in chopping is referred to as the “rounding” bit. The value of a rounded result is related to the chopped result as follows:

- If the rounding bit is 1, the rounded result is the chopped result incremented by an LSB (least significant bit).
- If the rounding bit is zero, the rounded and chopped results are identical.

## VAX Instruction Set

### REMQUE

All VAX processors implement rounding to produce results identical to the results produced by the following algorithm: add a 1 to the rounding bit and propagate the carry, if it occurs. Note that a renormalization may be required after rounding takes place. If this occurs, the new rounding bit will be 0; therefore, it can occur only once. The following statements summarize the relations among chopped, rounded, and true (infinite precision) results:

- If a stored result is exact:
  - $roundedvalue = choppedvalue = truevalue$
- If a stored result is not exact:
  - Its magnitude is always less than that of the true result for chopping.
  - Its magnitude is always less than that of the true result for rounding if the rounding bit is zero.
  - Its magnitude is greater than that of the true result for rounding if the rounding bit is 1.

#### 9.2.8.4 Instruction Descriptions

The following instructions are described in this section:

|     | Description and Opcode   | Number of Instructions |
|-----|--|------------------------|
| 1.  | Add 2 Operand<br>ADD{F,D,G,H}2 add.rx, sum.mx  | 4                      |
| 2.  | Add 3 Operand<br>ADD{F,D,G,H}3 add1.rx, add2.rx, sum.wx  | 4                      |
| 3.  | Clear<br>CLR{L=F,Q=D=G,O=H} dst.wx   | 3                      |
| 4.  | Compare<br>CMP{F,D,G,H} src1.rx, src2.rx   | 4                      |
| 5.  | Convert<br>CVT{F,D,G,H}{B,W,L,F,D,G,H} src.rx, dst.wy<br>CVT{B,W,L}{F,D,G,H} src.rx, dst.wy<br>All pairs except FF,DD,GG,HH,DG, and GD     | 34                     |
| 6.  | Convert Rounded<br>CVTR{F,D,G,H}L src.rx, dst.wl   | 4                      |
| 7.  | Divide 2 Operand<br>DIV{F,D,G,H}2 divr.rx, quo.mx  | 4                      |
| 8.  | Divide 3 Operand<br>DIV{F,D,G,H}3 divr.rx, divd.rx, quo.wx   | 4                      |
| 9.  | Extended Modulus<br>EMOD{F,D} mulr.rx, mulrx.rb, muld.rx,<br>int.wl, fract.wx<br>EMOD{G,H} mulr.rx, mulrx.rw, muld.rx,<br>int.wl, fract.wx | 4                      |
| 10. | Move Negated<br>MNEG{F,D,G,H} src.rx, dst.wx   | 4                      |
| 11. | Move<br>MOV{F,D,G,H} src.rx, dst.wx  | 4                      |
| 12. | Multiply 2 Operand<br>MUL{F,D,G,H}2 mulr.rx, prod.mx   | 4                      |

|     | Description and Opcode  | Number of Instructions |
|-----|---|------------------------|
| 13. | Multiply 3 Operand<br>MUL{F,D,G,H}3 mulr.rx, muld.rx, prod.wx   | 4                      |
| 14. | Polynomial Evaluation F_floating<br>POLYF arg.rf, degree.rw, tbladdr.ab,<br>{R0-3.wl}                   | 1                      |
| 15. | Polynomial Evaluation D_floating<br>POLYD arg.rd, degree.rw, tbladdr.ab,<br>{R0-5.wl}                   | 1                      |
| 16. | Polynomial Evaluation G_floating<br>POLYG arg.rg, degree.rw, tbladdr.ab,<br>{R0-5.wl}                   | 1                      |
| 17. | Polynomial Evaluation H_floating<br>POLYH arg.rh, degree.rw, tbladdr.ab,<br>{R0-5.wl,-16(SP):-1(SP).wb} | 1                      |
| 18. | Subtract 2 Operand<br>SUB{F,D,G,H}2 sub.rx, dif.mx  | 4                      |
| 19. | Subtract 3 Operand<br>SUB{F,D,G,H}3 sub.rx, min.rx, dif.wx  | 4                      |
| 20. | Test<br>TST{F,D,G,H} src.rx   | 4                      |

The following floating-point instructions are described in Section 9.2.4.

|    | Description and Opcode  | Number of Instructions |
|----|---|------------------------|
| 1. | Add Compare and Branch<br>ACB{F,D,G,H} limit.rx, add.rx, index.mx,<br>displ.bw<br><br>Compare is LE on positive add, GE on<br>negative add. | 4                      |

## VAX Instruction Set

### ADD

---

## ADD

Add

### Format

2operand: opcode add.rx, sum.mx

3operand: opcode add1.rx, add2.rx, sum.wx

### Condition Codes

N ← sum LSS 0;

Z ← sum EQL 0;

V ← 0;

C ← 0;

### Exceptions

floating overflow  
floating underflow  
reserved operand

### Opcodes

|      |       |                          |
|------|-------|--------------------------|
| 40   | ADDF2 | Add F_floating 2 Operand |
| 41   | ADDF3 | Add F_floating 3 Operand |
| 60   | ADDD2 | Add D_floating 2 Operand |
| 61   | ADDD3 | Add D_floating 3 Operand |
| 40FD | ADDG2 | Add G_floating 2 Operand |
| 41FD | ADDG3 | Add G_floating 3 Operand |
| 60FD | ADDH2 | Add H_floating 2 Operand |
| 61FD | ADDH3 | Add H_floating 3 Operand |

### Description

In 2 operand format, the addend operand is added to the sum operand, and the sum operand is replaced by the rounded result. In 3 operand format, the addend 1 operand is added to the addend 2 operand, and the sum operand is replaced by the rounded result.

#### Notes

1. On a reserved operand fault, the sum operand is unaffected, and the condition codes are UNPREDICTABLE.
2. On floating underflow, if FU is set, a fault occurs. Zero is stored as the result of floating underflow only if FU is clear. On a floating underflow fault, the sum operand is unaffected. If FU is clear, the sum operand is replaced by zero, and no exception occurs.
3. On floating overflow, the instruction faults, the sum operand is unaffected, and the condition codes are UNPREDICTABLE.

---

## CLR

Clear

### Format

opcode dst.wx

### Condition Codes

N ← 0;  
Z ← 1;  
V ← 0;  
C ← C;

### Exceptions

None.

### Opcodes

|      |      |                   |
|------|------|-------------------|
| D4   | CLRF | Clear F_floating  |
| 7C   | CLRD | Clear D_floating, |
|      | CLRG | Clear G_floating  |
| 7CFD | CLRH | Clear H_floating  |

### Description

The destination operand is replaced by zero.

#### Note

CLR $x$  **dst** is equivalent to MOV $x$  S<sup>#0</sup>, **dst**, but is 1 byte shorter.

## CMP

Compare

### Format

opcode src1.rx, src2.rx

### Condition Codes

N ← src1 LSS src2;  
Z ← src1 EQL src2;  
V ← 0;  
C ← 0;

### Exceptions

reserved operand

### Opcodes

|      |      |                    |
|------|------|--------------------|
| 51   | CMPF | Compare F_floating |
| 71   | CMPD | Compare D_floating |
| 51FD | CMPG | Compare G_floating |
| 71FD | CMPH | Compare H_floating |

### Description

The source 1 operand is compared with the source 2 operand. The only action is to affect the condition codes.

## CVT

Convert

### Format

opcode src.rx, dst.wy

### Condition Codes

N ← dst LSS 0;  
 Z ← dst EQL 0;  
 V ← {integer overflow};  
 C ← 0;

### Exceptions

integer overflow  
 floating overflow  
 floating underflow  
 reserved operand

### Opcodes

|      |       |                            |
|------|-------|----------------------------|
| 4C   | CVTBF | Convert Byte to F_floating |
| 6C   | CVTBD | Convert Byte to D_floating |
| 4CFD | CVTBG | Convert Byte to G_floating |
| 6CFD | CVTBH | Convert Byte to H_floating |
| 4D   | CVTWF | Convert Word to F_floating |
| 6D   | CVTWD | Convert Word to D_floating |
| 4DFD | CVTWG | Convert Word to G_floating |
| 6DFD | CVTWH | Convert Word to H_floating |
| 4E   | CVTLF | Convert Long to F_floating |
| 6E   | CVTLD | Convert Long to D_floating |
| 4EFD | CVTLG | Convert Long to G_floating |
| 6EFD | CVTLH | Convert Long to H_floating |
| 48   | CVTFB | Convert F_floating to Byte |
| 68   | CVTDB | Convert D_floating to Byte |
| 48FD | CVTGB | Convert G_floating to Byte |
| 68FD | CVTHB | Convert H_floating to Byte |
| 49   | CVTFW | Convert F_floating to Word |
| 69   | CVTDW | Convert D_floating to Word |
| 49FD | CVTGW | Convert G_floating to Word |
| 69FD | CVTHW | Convert H_floating to Word |
| 4A   | CVTFL | Convert F_floating to Long |

## VAX Instruction Set

### CVT

|      |        |                                    |
|------|--------|------------------------------------|
| 4B   | CVTRFL | Convert Rounded F_floating to Long |
| 6A   | CVTDL  | Convert D_floating to Long         |
| 6B   | CVTRDL | Convert Rounded D_floating to Long |
| 4AFD | CVTGL  | Convert G_floating to Long         |
| 4BFD | CVTRGL | Convert Rounded G_floating to Long |
| 6AFD | CVTHL  | Convert H_floating to Long         |
| 6BFD | CVTRHL | Convert Rounded H_floating to Long |
| 56   | CVTFD  | Convert F_floating to D_floating   |
| 99FD | CVTFG  | Convert F_floating to G_floating   |
| 98FD | CVTFH  | Convert F_floating to H_floating   |
| 76   | CVTDF  | Convert D_floating to F_floating   |
| 32FD | CVTDH  | Convert D_floating to H_floating   |
| 33FD | CVTGF  | Convert G_floating to F_floating   |
| 56FD | CVTGH  | Convert G_floating to H_floating   |
| F6FD | CVTHF  | Convert H_floating to F_floating   |
| F7FD | CVTHD  | Convert H_floating to D_floating   |
| 76FD | CVTHG  | Convert H_floating to G_floating   |

### Description

The source operand is converted to the data type of the destination operand, and the destination operand is replaced by the result. The form of the conversion is as follows:

| Form      | Instructions   |
|-----------|--|
| Exact     | CVTBF, CVTBD, CVTBG, CVTBH, CVTWF, CVTWD, CVTWG, CVTWH, CVTLD, CVTLG, CVTLH, CVTFD, CVTFG, CVTFH, CVTDH, CVTGH |
| Truncated | CVTFB, CVTDB, CVTGB, CVTHB, CVTFW, CVTDW, CVTGW, CVTHW, CVTFL, CVTDL, CVTGL, CVTHL                             |
| Rounded   | CVTLF, CVTRFL, CVTRDL, CVTRGL, CVTRHL, CVTDF, CVTGF, CVTHF, CVTHD, CVTHG                                       |

### Notes

1. Only CVTDF, CVTGF, CVTHF, CVTHD, and CVTHG can result in a floating overflow fault; the destination operand is unaffected, and the condition codes are UNPREDICTABLE.
2. Only converts with a floating-point source operand can result in a reserved operand fault. On a reserved operand fault, the destination operand is unaffected, and the condition codes are UNPREDICTABLE.
3. Only converts with an integer destination operand can result in integer overflow. On integer overflow, the destination operand is replaced by the low-order bits of the true result.
4. Only CVTGF, CVTHF, CVTHD, and CVTHG can result in floating underflow. If FU is set, a fault occurs. On a floating underflow fault, the destination operand is unaffected. If FU is clear, the destination operand is replaced by zero, and no exception occurs.

## DIV

Divide

### Format

2operand: opcode divr.rx, quo.mx  
3operand: opcode divr.rx, divd.rx, quo.wx

### Condition Codes

N <— quo LSS 0;  
Z <— quo EQL 0;  
V <— 0;  
C <— 0;

### Exceptions

floating overflow  
floating underflow  
divide by zero  
reserved operand

### Opcodes

|      |       |                             |
|------|-------|-----------------------------|
| 46   | DIVF2 | Divide F_floating 2 Operand |
| 47   | DIVF3 | Divide F_floating 3 Operand |
| 66   | DIVD2 | Divide D_floating 2 Operand |
| 67   | DIVD3 | Divide D_floating 3 Operand |
| 46FD | DIVG2 | Divide G_floating 2 Operand |
| 47FD | DIVG3 | Divide G_floating 3 Operand |
| 66FD | DIVH2 | Divide H_floating 2 Operand |
| 67FD | DIVH3 | Divide H_floating 3 Operand |

### Description

In 2 operand format, the quotient operand is divided by the divisor operand and the quotient operand is replaced by the rounded result. In 3 operand format, the dividend operand is divided by the divisor operand, and the quotient operand is replaced by the rounded result.

#### Notes

1. On a reserved operand fault, the quotient operand is unaffected, and the condition codes are UNPREDICTABLE.
2. On floating underflow, if FU is set, a fault occurs. On a floating underflow fault, the quotient operand is unaffected. If FU is clear, the quotient operand is replaced by zero, and no exception occurs.

## VAX Instruction Set

### DIV

3. On floating overflow, the instruction faults, the quotient operand is unaffected, and the condition codes are UNPREDICTABLE.
4. On divide by zero, the quotient operand and condition codes are affected, as in note 3.

## EMOD

Extended Multiply and Integerize

### Format

EMODF and EMODD:

opcode mulr.rx, mulrx.rb, muld.rx, int.wl, fract.wx

EMODG and EMODH:

opcode mulr.rx, mulrx.rw, muld.rx, int.wl, fract.wx

### Condition Codes

N ← fract LSS 0;  
 Z ← fract EQL 0;  
 V ← {integer overflow};  
 C ← 0;

### Exceptions

integer overflow  
 floating underflow  
 reserved operand

### Opcodes

|      |       |   |
|------|-------|---|
| 54   | EMODF | Extended Multiply and Integerize F_floating |
| 74   | EMODD | Extended Multiply and Integerize D_floating |
| 54FD | EMODG | Extended Multiply and Integerize G_floating |
| 74FD | EMODH | Extended Multiply and Integerize H_floating |

### Description

The multiplier extension operand is concatenated with the multiplier operand to gain 8 (EMODD and EMODF), 11 (EMODG), or 15 (EMODH) additional low-order fraction bits. The low-order 5 or 1 bits of the 16-bit multiplier extension operand are ignored by the EMODG and EMODH instructions, respectively. The multiplicand operand is multiplied by the extended multiplier operand. The multiplication result is equivalent to the exact product truncated (before normalization) to a fraction field of 32 bits in F\_floating, 64 bits in D\_floating and G\_floating, and 128 bits in H\_floating. The result is regarded as the sum of an integer and fraction of the same sign. The integer operand is replaced by the integer part of the result, and the fraction operand is replaced by the rounded fractional part of the result.

## VAX Instruction Set

### EMOD

#### Notes

1. On a reserved operand fault, the integer operand, and the fraction operand are unaffected. The condition codes are UNPREDICTABLE.
2. On floating underflow, if FU is set, a fault occurs. On a floating underflow fault, the integer and fraction parts are unaffected. If FU is clear, the integer and fraction parts are replaced by zero, and no exception occurs.
3. On integer overflow, the integer operand is replaced by the low-order bits of the true result.
4. Floating overflow is indicated by integer overflow; however, integer overflow is possible in the absence of floating overflow.
5. The signs of the integer and fraction are the same unless integer overflow results.
6. Because the fraction part is rounded after separation of the integer part, it is possible that the value of the fraction operand is 1.

---

## MNEG

Move Negated

### Format

opcode src.rx, dst.wx

### Condition Codes

N ← dst LSS 0;  
 Z ← dst EQL 0;  
 V ← 0;  
 C ← 0;

### Exceptions

reserved operand

### Opcodes

|      |       |                         |
|------|-------|-------------------------|
| 52   | MNEGF | Move Negated F_floating |
| 72   | MNEGD | Move Negated D_floating |
| 52FD | MNEGG | Move Negated G_floating |
| 72FD | MNEGH | Move Negated H_floating |

### Description

The destination operand is replaced by the negative of the source operand.

## VAX Instruction Set

### MOV

---

## MOV

Move

### Format

opcode src.rx, dst.wx

### Condition Codes

N ← dst LSS 0;  
Z ← dst EQL 0;  
V ← 0;  
C ← C;

### Exceptions

reserved operand

### Opcodes

|      |      |                 |
|------|------|-----------------|
| 50   | MOVF | Move F_floating |
| 70   | MOVD | Move D_floating |
| 50FD | MOVG | Move G_floating |
| 70FD | MOVH | Move H_floating |

### Description

The destination operand is replaced by the source operand.

#### Note

On a reserved operand fault, the destination operand is unaffected, and the condition codes are UNPREDICTABLE.

## MUL

Multiply

### Format

2operand: opcode mulr.rx, prod.mx

3operand: opcode mulr.rx, muld.rx, prod.wx

### Condition Codes

N ← prod LSS 0;

Z ← prod EQL 0;

V ← 0;

C ← 0;

### Exceptions

floating overflow  
floating underflow  
reserved operand

### Opcodes

|      |       |                               |
|------|-------|-------------------------------|
| 44   | MULF2 | Multiply F_floating 2 Operand |
| 45   | MULF3 | Multiply F_floating 3 Operand |
| 64   | MULD2 | Multiply D_floating 2 Operand |
| 65   | MULD3 | Multiply D_floating 3 Operand |
| 44FD | MULG2 | Multiply G_floating 2 Operand |
| 45FD | MULG3 | Multiply G_floating 3 Operand |
| 64FD | MULH2 | Multiply H_floating 2 Operand |
| 65FD | MULH3 | Multiply H_floating 3 Operand |

### Description

In 2 operand format, the product operand is multiplied by the multiplier operand, and the product operand is replaced by the rounded result. In 3 operand format, the multiplicand operand is multiplied by the multiplier operand, and the product operand is replaced by the rounded result.

#### Notes

1. On a reserved operand fault, the product operand is unaffected, and the condition codes are UNPREDICTABLE.
2. On floating underflow, if FU is set, a fault occurs. On a floating underflow fault, the product operand is unaffected. If FU is clear, the product operand is replaced by zero, and no exception occurs.
3. On floating overflow, the instruction faults, the product operand is unaffected, and the condition codes are UNPREDICTABLE.

## POLY

Polynomial Evaluation

### Format

opcode arg.rx, degree.rw, tbladdr.ab

### Condition Codes

N ← R0 LSS 0;  
Z ← R0 EQL 0;  
V ← 0;  
C ← 0;

### Exceptions

floating overflow  
floating underflow  
reserved operand

### Opcodes

|      |       |                                  |
|------|-------|----------------------------------|
| 55   | POLYF | Polynomial Evaluation F_floating |
| 75   | POLYD | Polynomial Evaluation D_floating |
| 55FD | POLYG | Polynomial Evaluation G_floating |
| 75FD | POLYH | Polynomial Evaluation H_floating |

### Description

The table address operand points to a table of polynomial coefficients. The coefficient of the highest-order term of the polynomial is pointed to by the table address operand. The table is specified with lower-order coefficients stored at increasing addresses. The data type of the coefficients is the same as the data type of the argument operand. The evaluation is carried out by Horner's method, and the contents of R0 (R1'R0 for POLYD and POLYG, R3'R2'R1'R0 for POLYH) are replaced by the result. The result computed is:

```
if d = degree
and x = arg
result = C[0]+x**0 + x*(C[1] + x*(C[2] + ... x*C[d]))
```

The unsigned word degree operand specifies the highest-numbered coefficient to participate in the evaluation. POLYH requires four longwords on the stack to store **arg** in case the instruction is interrupted.

### Notes

1. After execution:

POLYF:  
R0 = result  
R1 = 0  
R2 = 0  
R3 = table address + degree\*4 + 4

POLYD and POLYG:

R0 = high-order part of result  
 R1 = low-order part of result  
 R2 = 0  
 R3 = table address + degree\*8 + 8  
 R4 = 0  
 R5 = 0

POLYH:

R0 = highest-order part of result  
 R1 = second-highest-order part of result  
 R2 = second-lowest-order part of result  
 R3 = lowest-order part of result  
 R4 = 0  
 R5 = table address + degree\*16 + 16

2. On a floating fault:

- If PSL<FPD> = 0, the instruction faults, and all relevant side effects are restored to their original state.
- If PSL<FPD> = 1, the instruction is suspended, and the state is saved in the general registers as follows:

```
POLYF:
R0 = tmp3           ! Partial result after iteration
                   !   prior to the one causing the
                   !   overflow/underflow

R1 = arg
R2<7:0> = tmp1      ! Number of iterations remaining
R2<31:8> = implementation specific
R3 = tmp2           ! Points to table entry causing
                   !   exception
```

```
POLYD and POLYG:
R1'R0 = tmp3       ! Partial result after iteration
                   !   prior to the one causing the
                   !   overflow/underflow

R2<7:0> = tmp1      ! Number of iterations remaining
R2<31:8> = implementation specific
R3 = tmp2           ! Points to table entry causing
                   !   exception

R5'R4 = arg
```

```
POLYH:
R3'R2'R1'R0 = tmp3 ! Partial result after iteration
                   !   prior to the one causing the
                   !   overflow/underflow

R4<7:0> = tmp1      ! Number of iterations remaining
R4<31:8> = implementation specific
R5 = tmp2           ! Points to table entry causing
                   !   exception
```

**arg** is saved on the stack in use during the faulting instruction.

Implementation-specific information is saved to allow the instruction to continue after possible scaling of the coefficients and partial result by the fault handler.

3. If the unsigned word degree operand is zero and the argument is not a reserved operand, the result is C[0].
4. If the unsigned word degree operand is greater than 31, a reserved operand fault occurs.

## VAX Instruction Set

### POLY

5. On a reserved operand fault:
  - If PSL<FPD> = 0, the reserved operand is either the degree operand (greater than 31), or the argument operand, or some coefficient.
  - If PSL<FPD> = 1, the reserved operand is a coefficient, and R3 (except for POLYH) or R5 (for POLYH) is pointing at the value that caused the exception.
  - The state of the saved condition codes and the other registers is UNPREDICTABLE. If the reserved operand is changed and the contents of the condition codes and all registers are preserved, the fault can be continued.
6. On floating underflow after the rounding operation at any iteration of the computation loop, a fault occurs if FU is set. If FU is clear, the temporary result (**tmp3**) is replaced by zero and the operation continues. In this case, the final result may be nonzero if underflow occurred before the last iteration.
7. On floating overflow after the rounding operation at any iteration of the computation loop, the instruction terminates with a fault.
8. If the argument is zero and one of the coefficients in the table is the reserved operand, whether a reserved operand fault occurs is UNPREDICTABLE.
9. For POLYH, some implementations may not save **arg** on the stack until after an interrupt or fault occurs. However, **arg** will always be on the stack if an interrupt or floating fault occurs after FPD is set. If the four longwords on the stack overlap any of the source operands, the results are UNPREDICTABLE.

### Example

```
; To compute P(x) = C0 + C1*x + C2*x**2
; where C0 = 1.0, C1 = .5, and C2 = .25
      POLYF   X,#2,PTABLE
      .
      .
      .
PTABLE: .FLOAT 0.25   ; C2
        .FLOAT 0.5   ; C1
        .FLOAT 1.0   ; C0
```

---

**SUB**

Subtract

**Format**

2operand: opcode sub.rx, dif.mx

3operand: opcode sub.rx, min.rx, dif.wx

**Condition Codes**

N ← dif LSS 0;

Z ← dif EQL 0;

V ← 0;

C ← 0;

**Exceptions**floating overflow  
floating underflow  
reserved operand**Opcodes**

|      |       |                               |
|------|-------|-------------------------------|
| 42   | SUBF2 | Subtract F_floating 2 Operand |
| 43   | SUBF3 | Subtract F_floating 3 Operand |
| 62   | SUBD2 | Subtract D_floating 2 Operand |
| 63   | SUBD3 | Subtract D_floating 3 Operand |
| 42FD | SUBG2 | Subtract G_floating 2 Operand |
| 43FD | SUBG3 | Subtract G_floating 3 Operand |
| 62FD | SUBH2 | Subtract H_floating 2 Operand |
| 63FD | SUBH3 | Subtract H_floating 3 Operand |

**Description**

In 2 operand format, the subtrahend operand is subtracted from the difference operand, and the difference is replaced by the rounded result. In 3 operand format, the subtrahend operand is subtracted from the minuend operand, and the difference operand is replaced by the rounded result.

## VAX Instruction Set

### SUB

#### Notes

1. On a reserved operand fault, the difference operand is unaffected, and the condition codes are UNPREDICTABLE.
2. On floating underflow, if FU is set, a fault occurs. Zero is stored as the result of floating underflow only if FU is clear. On a floating underflow fault, the difference operand is unaffected. If FU is clear, the difference operand is replaced by zero, and no exception occurs.
3. On floating overflow, the instruction faults, the difference operand is unaffected, and the condition codes are UNPREDICTABLE.

---

## TST

Test

### Format

opcode src.rx

### Condition Codes

N ← src LSS 0;  
Z ← src EQL 0;  
V ← 0;  
C ← 0;

### Exceptions

reserved operand

### Opcodes

|      |      |                 |
|------|------|-----------------|
| 53   | TSTF | Test F_floating |
| 73   | TSTD | Test D_floating |
| 53FD | TSTG | Test G_floating |
| 73FD | TSTH | Test H_floating |

### Description

The condition codes are affected according to the value of the source operand.

#### Notes

1. TSTx **src** is equivalent to CMPx **src**, #0, but is 5 (F\_floating) or 9 (D\_floating or G\_floating) or 17 (H\_floating) bytes shorter.
2. On a reserved operand fault, the condition codes are UNPREDICTABLE.

### 9.2.9 Character String Instructions

A character string is specified by the following two operands:

1. An unsigned word operand that specifies the length of the character string in bytes.
2. The address of the lowest-addressed byte of the character string. This is specified by a byte operand of address access type.

Each of the character string instructions uses general registers R0 to R1, R0 to R3, or R0 to R5 to contain a control block that maintains updated addresses and state during the execution of the instruction. At completion, these registers are available to software to use as string specification operands for a subsequent instruction on a contiguous character string. During the execution of the instructions, pending interrupt conditions are tested. If any conditions are found, the control block is updated, a first-part-done bit is set in the processor status longword (PSL), and the instruction is interrupted (refer to Appendix E). After the interruption, the instruction resumes transparently. The format of the control block is as follows:

|           |          |      |
|-----------|----------|------|
|           | LENGTH 1 | : R0 |
| ADDRESS 1 |          | : R1 |
|           | LENGTH 2 | : R2 |
| ADDRESS 2 |          | : R3 |
|           | LENGTH 3 | : R4 |
| ADDRESS 3 |          | : R5 |

ZK-1175A-GE

The fields LENGTH 1, LENGTH 2 (if required), and LENGTH 3 (if required) contain the number of bytes remaining to be processed in the first, second, and third string operands, respectively. The fields ADDRESS 1, ADDRESS 2 (if required), and ADDRESS 3 (if required) contain the address of the next byte to be processed in the first, second, and third string operands, respectively.

Memory access faults do not occur when a zero-length string is specified because no memory reference occurs.

The following instructions are described in this section.

|    | Description and Opcode   | Number of Instructions |
|----|--|------------------------|
| 1. | Compare Characters 3 Operand<br>CMPC3 len.rw, src1addr.ab, src2addr.ab, {R0-3.wl}                          | 1                      |
| 2. | Compare Characters 5 Operand<br>CMPC5 src1len.rw, src1addr.ab, fill.rb, src2len.rw, src2addr.ab, {R0-3.wl} | 1                      |
| 3. | Locate Character<br>LOCC char.rb, len.rw, addr.ab, {R0-1.wl}   | 1                      |

|     | Description and Opcode  | Number of Instructions |
|-----|---|------------------------|
| 4.  | Match Characters<br>MATCHC len1.rw, addr1.ab, len2.rw, addr2.ab, {R0-3.wl}  | 1                      |
| 5.  | Move Character 3 Operand<br>MOVC3 len.rw, srcaddr.ab, dstaddr.ab, {R0-5.wl}   | 1                      |
| 6.  | Move Character 5 Operand<br>MOVC5 srclen.rw, srcaddr.ab, fill.rb, dstlen.rw, dstaddr.ab, {R0-5.wl}                    | 1                      |
| 7.  | Move Translated Characters<br>MOVTC srclen.rw, srcaddr.ab, fill.rb, tbladdr.ab, dstlen.rw, dstaddr.ab, {R0-5.wl}      | 1                      |
| 8.  | Move Translated Until Character<br>MOVTUC srclen.rw, srcaddr.ab, esc.rb, tbladdr.ab, dstlen.rw, dstaddr.ab, {R0-5.wl} | 1                      |
| 9.  | Scan Characters<br>SCANC len.rw, addr.ab, tbladdr.ab, mask.rb, {R0-3.wl}  | 1                      |
| 10. | Skip Character<br>SKPC char.rb, len.rw, addr.ab, {R0-1.wl}  | 1                      |
| 11. | Span Characters<br>SPANC len.rw, addr.ab, tbladdr.ab, mask.rb, {R0-3.wl}  | 1                      |

## CMPC

Compare Characters

### Format

3operand: opcode len.rw, src1addr.ab,  
src2addr.ab  
5operand: opcode src1len.rw, src1addr.ab, fill.rb,  
src2len.rw, src2addr.ab

### Condition Codes

N <— {first byte} LSS {second byte};  
Z <— {first byte} EQL {second byte};  
V <— 0;  
C <— {first byte} LSSU {second byte};

### Exceptions

None.

### Opcodes

|    |       |                              |
|----|-------|------------------------------|
| 29 | CMPC3 | Compare Characters 3 Operand |
| 2D | CMPC5 | Compare Characters 5 Operand |

### Description

In 3 operand format, the bytes of string1 specified by the length and address1 operands are compared with the bytes of string2 specified by the length and address2 operands. Comparison proceeds until inequality is detected or all the bytes of the strings have been examined. Condition codes are affected by the result of the last byte comparison. In 5 operand format, the bytes of the string1 operand specified by the length1 and address1 operands are compared with the bytes of the string2 operand specified by the length2 and address2 operands. If one string is longer than the other, the shorter string is conceptually extended to the length of the longer by appending (at higher addresses) bytes equal to the fill operand. Comparison proceeds until inequality is detected or all the bytes of the strings have been examined. Condition codes are affected by the result of the last byte comparison. For either CMPC3 or CMPC5, two zero-length strings compare equal (that is, Z is set and N, V, and C are cleared).

#### Notes

1. After execution of CMPC3:
  - R0 = Number of bytes remaining in string1 (including byte that terminated comparison); R0 is zero only if strings are equal
  - R1 = Address of the byte in string1 that terminated comparison; if strings are equal, address of 1 byte beyond string1

R2 = R0

R3 = Address of the byte in string2 that terminated comparison; if strings are equal, address of 1 byte beyond string2

2. After execution of CMPC5:

R0 = Number of bytes remaining in string1 (including byte that terminated comparison); R0 is zero only if string1 and string2 are of equal length and equal or string1 was exhausted before comparison terminated

R1 = Address of the byte in string1 that terminated comparison; if comparison did not terminate before string1 exhausted, address of 1 byte beyond string1

R2 = Number of bytes remaining in string2 (including byte that terminated comparison); R2 is zero only if string2 and string1 are of equal length or string2 was exhausted before comparison terminated

R3 = Address of the byte in string2 that terminated comparison; if comparison did not terminate before string2 was exhausted, address of 1 byte beyond string2

3. If both strings have zero length, condition code Z is set and N, V, and C are cleared just as in the case of two equal strings.

## LOCC

Locate Character

### Format

opcode char.rb, len.rw, addr.ab

### Condition Codes

N ← 0;  
Z ← R0 EQL 0;  
V ← 0;  
C ← 0;

### Exceptions

None.

### Opcodes

3A LOCC Locate Character

### Description

The character operand is compared with the bytes of the string specified by the length and address operands. Comparison continues until equality is detected or all bytes of the string have been compared. If equality is detected, the condition code Z-bit is cleared; otherwise, the Z-bit is set.

#### Notes

1. After execution:
  - R0 = Number of bytes remaining in the string (including located one) if byte located; otherwise, zero
  - R1 = Address of the byte located if byte located; otherwise, address of 1 byte beyond the string
2. If the string has zero length, condition code Z is set just as though each byte of the entire string were unequal to character.

---

## MATCHC

Match Characters

### Format

opcode    objlen.rw, objaddr.ab, srclen.rw, srcaddr.ab

### Condition Codes

N    <—    0;  
 Z    <—    R0 EQL 0; !match found  
 V    <—    0;  
 C    <—    0;

### Exceptions

None.

### Opcodes

39        MATCHC                    Match Characters

### Description

The source string specified by the source length and source address operands is searched for a substring that matches the object string specified by the object length and object address operands. If the substring is found, the condition code Z-bit is set; otherwise, it is cleared.

#### Notes

- After execution:
  - R0 =    If a match occurred, zero; otherwise, the number of bytes in the object string
  - R1 =    If a match occurred, the address of 1 byte beyond the object string; that is, **objaddr + objlen**; otherwise, the address of the object string
  - R2 =    If a match occurred, the number of bytes remaining in the source string; otherwise, zero
  - R3 =    If a match occurred, the address of 1 byte beyond the last byte matched; otherwise, the address of 1 byte beyond the source string; that is, **srcaddr + srclen**

For zero-length source and object strings, R3 and R1 contain the source and object addresses, respectively.
- If both strings have zero length, or if the object string has zero length, condition code Z is set, and registers R0 to R3 are left just as though the substring were found.
- If the source string has zero length and the object string has nonzero length, condition code Z is cleared, and registers R0 to R3 are left just as though the substring were not found.

# VAX Instruction Set

## MOVC

---

### MOVC

Move Character

#### Format

3operand: opcode len.rw, srcaddr.ab, dstaddr.ab  
5operand: opcode srclen.rw, srcaddr.ab, fill.rb,  
dstlen.rw, dstaddr.ab

#### Condition Codes

N <— 0; !MOVC3  
Z <— 1;  
V <— 0;  
C <— 0;

N <— srclen LSS dstlen; !MOVC5  
Z <— srclen EQL dstlen;  
V <— 0;  
C <— srclen LSSU dstlen;

#### Exceptions

None.

#### Opcodes

|    |       |                          |
|----|-------|--------------------------|
| 28 | MOVC3 | Move Character 3 Operand |
| 2C | MOVC5 | Move Character 5 Operand |

#### Description

In 3 operand format, the destination string specified by the length and destination address operands is replaced by the source string specified by the length and source address operands. In 5 operand format, the destination string specified by the destination length and destination address operands is replaced by the source string specified by the source length and source address operands. If the destination string is longer than the source string, the highest-addressed bytes of the destination are replaced by the fill operand. If the destination string is shorter than the source string, the highest-addressed bytes of the source string are not moved. The operation of the instruction is such that overlap of the source and destination strings does not affect the result.

#### Notes

1. After execution of MOVC3:

R0 = 0

R1 = Address of 1 byte beyond the source string

R2 = 0  
R3 = Address of 1 byte beyond the destination string  
R4 = 0  
R5 = 0

2. After execution of MOVC5:

R0 = Number of unmoved bytes remaining in source string. R0 is nonzero only if source string is longer than destination string  
R1 = Address of 1 byte beyond last byte in source that was moved  
R2 = 0  
R3 = Address of 1 byte beyond the destination string  
R4 = 0  
R5 = 0

3. MOVC3 is the preferred way to copy one block of memory to another.
4. MOVC5 with a zero source length operand is the preferred way to fill a block of memory with the fill character.

## MOVTC

Move Translated Characters

### Format

opcode    srclen.rw, srcaddr.ab, fill.rb, tbladdr.ab,  
          dstlen.rw, dstaddr.ab

### Condition Codes

N    <—    srclen LSS dstlen;  
Z    <—    srclen EQL dstlen;  
V    <—    0;  
C    <—    srclen LSSU dstlen;

### Exceptions

None.

### Opcodes

2E       MOVTC                    Move Translated Characters

### Description

The source string specified by the source length and source address operands is translated. It replaces the destination string specified by the destination length and destination address operands. Translation is accomplished by using each byte of the source string as an index into a 256-byte table whose first entry (entry number 0) address is specified by the table address operand. The byte selected replaces the byte of the destination string. If the destination string is longer than the source string, the highest-addressed bytes of the destination string are replaced by the fill operand. If the destination string is shorter than the source string, the highest-addressed bytes of the source string are not translated and moved. The operation of the instruction is such that overlap of the source and destination strings does not affect the result.

If the destination string overlaps the translation table, the destination string is UNPREDICTABLE.

**Notes**

1. After execution:

R0 = Number of untranslated bytes remaining in source string; R0 is nonzero only if source string is longer than destination string

R1 = Address of 1 byte beyond the last byte in source string that was translated

R2 = 0

R3 = Address of the translation table

R4 = 0

R5 = Address of 1 byte beyond the destination string

## MOVTUC

Move Translated Until Character

### Format

opcode    srclen.rw, srcaddr.ab, esc.rb, tbladdr.ab,  
          dstlen.rw, dstaddr.ab

### Condition Codes

N    <—    srclen LSS dstlen;  
Z    <—    srclen EQL dstlen;  
V    <—    {terminated by escape};  
C    <—    srclen LSSU dstlen;

### Exceptions

None.

### Opcodes

2F        MOVTUC                    Move Translated Until Character

### Description

The source string specified by the source length and source address operands is translated. It replaces the destination string specified by the destination length and destination address operands. Translation is accomplished by using each byte of the source string as an index into a 256-byte table whose first entry address (entry number 0) is specified by the table address operand. The byte selected replaces the byte of the destination string. Translation continues until a translated byte is equal to the escape byte, or until the source string or destination string is exhausted. If translation is terminated because of escape, the condition code V-bit is set; otherwise, it is cleared.

If the destination string overlaps the table, the destination string and registers R0 to R5 are UNPREDICTABLE. If the source and destination strings overlap and their addresses are not identical, the destination string and registers R0 to R5 are UNPREDICTABLE. If the source and destination string addresses are identical, the translation is performed correctly.

### Notes

1. After execution:

R0 =    Number of bytes remaining in source string (including the byte that caused the escape); R0 is zero only if the entire source string was translated and moved without escape  
R1 =    Address of the byte that resulted in destination string exhaustion or escape; or if no exhaustion or escape, address of 1 byte beyond the source string

- R2 = 0
- R3 = Address of the table
- R4 = Number of bytes remaining in the destination string
- R5 = Address of the byte in the destination string that would have received the translated byte that caused the escape or would have received a translated byte if the source string were not exhausted; or if no exhaustion or escape, the address of 1 byte beyond the destination string

## SCANC

Scan Characters

### Format

opcode    len.rw, addr.ab, tbladdr.ab, mask.rb

### Condition Codes

N     $\leftarrow$     0;  
Z     $\leftarrow$     R0 EQL 0;  
V     $\leftarrow$     0;  
C     $\leftarrow$     0;

### Exceptions

None.

### Opcodes

2A        SCANC                    Scan Characters

### Description

The assembler successively uses the bytes of the string specified by the length and address operands to index into a 256-byte table whose first entry (entry number 0) address is specified by the table address operand. The logical AND is performed on the byte selected from the table and the mask operand. The operation continues until the result of the AND is nonzero, or until all the bytes of the string have been exhausted. If a nonzero AND result is detected, the condition code Z-bit is cleared; otherwise, the Z-bit is set.

### Notes

1. After execution:
  - R0 =    Number of bytes remaining in the string (including the byte that produced the nonzero AND result); R0 is zero only if there was no nonzero AND result
  - R1 =    Address of the byte that produced the nonzero AND result; if no nonzero result, address of 1 byte beyond the string
  - R2 =    0
  - R3 =    Address of the table
2. If the string has zero length, condition code Z is set just as though the entire string were scanned.

---

## SKPC

Skip Character

### Format

opcode char.rb, len.rw, addr.ab

### Condition Codes

N ← 0;  
Z ← R0 EQL 0;  
V ← 0;  
C ← 0;

### Exceptions

None.

### Opcodes

3B SKPC Skip Character

### Description

The character operand is compared with the bytes of the string specified by the length and address operands. Comparison continues until inequality is detected or all bytes of the string have been compared. If inequality is detected, the condition code Z-bit is cleared; otherwise, the Z-bit is set.

#### Notes

1. After execution:
  - R0 = Number of bytes remaining in the string (including the unequal one) if unequal byte located; otherwise, zero
  - R1 = Address of the byte located if byte located; otherwise, address of 1 byte beyond the string
2. If the string has zero length, condition code Z is set just as though each byte of the entire string were equal to the character.

## SPANC

Span Characters

### Format

opcode len.rw, addr.ab, tbladdr.ab, mask.rb

### Condition Codes

N ← 0;  
Z ← R0 EQL 0;  
V ← 0;  
C ← 0;

### Exceptions

None.

### Opcodes

2B SPANC Span Characters

### Description

The assembler successively uses the bytes of the string specified by the length and address operands to index into a 256-byte table whose first entry (entry number 0) address is specified by the table address operand. The logical AND is performed on the byte selected from the table and the mask operand. The operation continues until the result of the AND is zero, or until all the bytes of the string have been exhausted. If a zero AND result is detected, the condition code Z-bit is cleared; otherwise, the Z-bit is set.

### Notes

- After execution:
  - R0 = Number of bytes remaining in the string (including the byte that produced the zero AND result); R0 is zero only if there was no zero AND result
  - R1 = Address of the byte that produced a zero AND result; if no nonzero result, address of 1 byte beyond the string
  - R2 = 0
  - R3 = Address of the table
- If the string has zero length, the condition code Z-bit is set just as though the entire string were spanned.

### 9.2.10 Cyclic Redundancy Check Instruction

This instruction implements the calculation of a cyclic redundancy check (CRC) string for any CRC polynomial up to 32 bits. Cyclic redundancy checking is an error detection method involving a division of the data stream by a CRC polynomial. The data stream is represented as a standard VAX string in memory. Error detection is accomplished by computing the CRC at the source and again at the destination, comparing the CRC computed at each end. The choice of the polynomial minimizes the number of undetected block errors of specific lengths. The choice of a CRC polynomial is not given here.

The operands of the CRC instruction are a string descriptor, a 16-longword table, and an initial CRC. The string descriptor is a standard VAX operand pair of the length of the string in bytes (up to 65,535) and the starting address of the string. The contents of the table are a function of the CRC polynomial to be used. It can be calculated from the polynomial by the algorithm in the notes. Several common CRC polynomials are also included in the notes. The system uses the initial CRC to start the polynomial correctly. Typically, the CRC has the value zero or -1. If the data stream is represented by a sequence of noncontiguous strings, the value would vary from 0 to -1.

The CRC instruction scans the string and includes each byte of the data stream in the CRC being calculated. The instruction includes the byte of the data stream by performing a logical exclusive OR (XOR) with it and the rightmost 8 bits of the CRC. Then the instruction shifts the CRC right 1 bit and inserts a zero on the left. The instruction uses the rightmost bit of the CRC (lost by the shift) to control the logical XOR operation of the CRC polynomial with the resultant CRC. If the bit is a 1, the instruction performs a logical XOR with the polynomial and the CRC. The instruction again shifts the CRC to the right and performs a conditional logical XOR on the polynomial with the result, for a total of eight times. The actual algorithm used can shift by 1, 2, or 4 bits at a time using the appropriate entries in a specially constructed table. The instruction produces a 32-bit CRC. For shorter polynomials, the result must be extracted from the 32-bit field. The data stream must be either a multiple of 8 bits in length or right-adjusted in the string with leading zero bits.

## CRC

Calculate Cyclic Redundancy Check

### Format

opcode   tbl.ab, inicrc.rl, strlen.rw, stream.ab

### Condition Codes

N   <—   R0 LSS 0;  
Z   <—   R0 EQL 0;  
V   <—   0;  
C   <—   0;

### Exceptions

None.

### Opcodes

0B       CRC                           Calculate Cyclic Redundancy Check

### Description

The CRC of the data stream described by the string descriptor is calculated. The initial CRC is given by **inicrc**; it is normally zero or -1, unless the CRC is calculated in several steps. The result is left in R0. If the polynomial is less than order 32, the result must be extracted from the low-order bits of R0. The CRC polynomial is expressed by the contents of the 16-longword table. See the notes for the calculation of the table.

#### Notes

1. After execution:  
R0 =   Result of CRC  
R1 =   0  
R2 =   0  
R3 =   Address 1 byte beyond the end of the source string
2. If the data stream is not a multiple of 8 bits, it must be right-adjusted with leading zero fill.
3. If the CRC polynomial is less than order 32, the result must be extracted from the low-order bits of R0.
4. Use the following algorithm to calculate the CRC table given a polynomial expressed:  
$$\text{polyn}\langle n \rangle \leftarrow \{\text{coefficient of } x^{\{\text{order} - 1 - n\}}\}$$

The following routine is system library routine LIB\$CRC\_TABLE (poly.r1, table.ab). The table is the location of the 64-byte (16-longword) table into which the result will be written.

```

SUBROUTINE LIB$CRC_TABLE (POLY, TABLE)
INTEGER*4 POLY, TABLE(0:15), TMP, X
DO 190 INDEX = 0, 15
    TMP = INDEX
    DO 150 I = 1, 4
        X = TMP .AND. 1
        TMP = ISHFT(TMP,-1)      !logical shift right one bit
        IF (X .EQ. 1) TMP = TMP .XOR. POLY
150    CONTINUE
        TABLE(INDEX) = TMP
190    CONTINUE
    RETURN
END

```

5. The following are descriptions of some commonly used CRC polynomials:

CRC-16 (used in DDCMP and Bisync)

```

polynomial:  x16 + x15 + x2 + 1
poly:        120001 (octal)
initialize:  0
result:      R0<15:0>

```

CCITT (used in ADCCP, HDLC, SDLC)

```

polynomial:  x16 + x12 + x5 + 1
poly:        102010 (octal)
initialize:  -1<15:0>
result:      one's complement of R0<15:0>

```

AUTODIN-II

```

polynomial:  x32+x26+x23+x22+x16+x12
             +x11+x10+x8+x7+x5+x4+x2+x+1
poly:        EDB88320 (hex)
initialize:  -1<31:0>
result:      one's complement of R0<31:0>

```

6. The CRC instruction produces an UNPREDICTABLE result unless the table is well-formed, like the one produced in note 3. Note that for any well-formed table, **entry**[0] is always zero and **entry**[8] is always the polynomial expressed as in note 3. The operation can be implemented using shifts of 1, 2, or 4 bits at a time, as follows:

| Shift (s) | Steps per Byte (limit) | Table Index | Table Index Multiplier (i) | Use Table Entries  |
|-----------|------------------------|-------------|----------------------------|--------------------|
| 1         | 8                      | tmp3<0>     | 8                          | [0]=0,[8]          |
| 2         | 4                      | tmp3<1:0>   | 4                          | [0]=0,[4],[8],[12] |
| 4         | 2                      | tmp3<3:0>   | 1                          | all                |

7. If the stream has zero length, R0 receives the initial CRC.

### 9.2.11 Decimal String Instructions

Decimal string instructions operate on packed decimal strings.

The decimal string instructions in this section operate on the following data types:

- Packed decimal string
- Trailing numeric string (overpunched and zoned)
- Leading separate numeric string

Where the phrase “decimal string” is used, it means any of the three data types. Conversion instructions are provided between the data types. Where necessary, a specific data type is identified.

A decimal string is specified by two operands:

1. For all decimal strings, the length is the number of digits in the string. The number of bytes in the string is a function of the length and the type of decimal string referenced (see Chapter 8).
2. The address of the lowest-addressed byte of the string. This byte contains the most significant digit for trailing numeric and packed decimal strings, as well as a sign for leading separate numeric strings. The address is specified by a byte operand of address access type.

Each of the decimal string instructions uses general registers R0 to R3 or R0 to R5 to hold a control block that maintains updated addresses and state during the execution of the instruction. At completion, the registers containing addresses are available to the software for use as string specification operands for a subsequent instruction on the same decimal strings.

During the execution of the instructions, pending interrupt conditions are tested; if any is found, the control block is updated. The first part done is set in the processor status longword (PSL), and the instruction is interrupted (refer to Appendix E). After the interruption, the instruction resumes transparently. The format of the control block at completion is as follows:

|           |   |      |
|-----------|---|------|
| 31        | 0 |      |
| 0         |   | : R0 |
| ADDRESS 1 |   | : R1 |
| 0         |   | : R2 |
| ADDRESS 2 |   | : R3 |
| 0         |   | : R4 |
| ADDRESS 3 |   | : R5 |

ZK-1176A-GE

The fields ADDRESS 1, ADDRESS 2, and ADDRESS 3 (if required) contain the address of the byte containing the most significant digit of the first, second, and third (if required) string operands, respectively.

The decimal string instructions treat decimal strings as integers with the decimal point assumed immediately beyond the least significant digit of the string. If a string in which a result is to be stored is longer than the result, its most significant digits are filled with zeros.

**9.2.11.1 Decimal Overflow**

Decimal overflow occurs if the destination string is too short to contain all of the digits (excluding leading zeros) of the result. On overflow, the destination string is replaced by the correctly signed least significant digits of the true result (even if the stored result is -0). Note that neither the high nibble of an even-length packed decimal string nor the sign byte of a leading separate numeric string is used to store result digits.

**9.2.11.2 Zero Numbers**

A zero result has a positive sign for all operations that complete without decimal overflow, except for CVTPT, which does not change a -0 to a +0. However, when digits are lost because of overflow, a zero result receives the sign (positive or negative) of the correct result.

A decimal string with value -0 is treated as identical to a decimal string with value +0. Thus, for example, +0 compares as equal to -0. When condition codes are affected on a -0 result, they are affected as if the result were +0; that is, N is cleared and Z is set.

**9.2.11.3 Reserved Operand Exception**

A reserved operand abort occurs if the length of a decimal string operand is outside the range 0 to 31, or if an invalid sign or digit is encountered in CVTSP or CVTTP. The program counter (PC) points to the opcode of the instruction causing the exception.

**9.2.11.4 UNPREDICTABLE Results**

The result of any operation is UNPREDICTABLE if any source decimal string operand contains invalid data. Except for CVTSP and CVTTP, the decimal string instructions do not verify the validity of source operand data.

If the destination operands overlap any source operands, the result of an operation will be UNPREDICTABLE. The destination strings, registers used by the instruction, and condition codes will be UNPREDICTABLE when a reserved operand abort occurs.

**9.2.11.5 Packed Decimal Operations**

Packed decimal strings generated by the decimal string instructions always have the preferred sign representation: 12 for "+" and 13 for "-". An even-length packed decimal string is always generated with a "0" digit in the high nibble of the first byte of the string.

## VAX Instruction Set

### CRC

A packed decimal string contains an invalid nibble if:

- A digit occurs in the sign position
- A sign occurs in a digit position
- A nonzero nibble occurs in the high-order nibble of the lowest-addressed byte in an even length string

#### 9.2.11.6 Zero-Length Decimal Strings

The length of a packed decimal string can be zero. In this case, the value is zero (plus or minus) and 1 byte of storage is occupied. This byte must contain a “0” digit in the high nibble and the sign in the low nibble.

The length of a trailing numeric string can be zero. In this case, no storage is occupied by the string. If a destination operand is a zero-length trailing numeric string, the sign of the operation is lost. Memory access faults do not occur when a zero-length trailing numeric operand is specified because no memory reference occurs. The value of a zero-length trailing numeric string is identically zero.

The length of a leading separate numeric string can be zero. In this case, 1 byte of storage is occupied by the sign. Memory is accessed when a zero-length operand is specified, and a reserved operand abort will occur if an invalid sign is detected. The value of a zero-length leading separate numeric string is zero.

#### 9.2.11.7 Instruction Descriptions

The following instructions are described in this section:

|    | Description and Opcode  | Number of Instructions |
|----|---|------------------------|
| 1. | Add Packed 4 Operand<br>ADDP4 addlen.rw, addaddr.ab, sumlen.rw,<br>sumaddr.ab, {R0-3.wl}                                  | 1                      |
| 2. | Add Packed 6 Operand<br>ADDP6 add1len.rw, add1addr.ab, add2len.rw,<br>add2addr.ab, sumlen.rw, sumaddr.ab,<br>{R0-5.wl}    | 1                      |
| 3. | Arithmetic Shift and Round Packed<br>ASHP cnt.rb, srclen.rw, srcaddr.ab,<br>round.rb, dstlen.rw, dstaddr.ab,<br>{R0-3.wl} | 1                      |
| 4. | Compare Packed 3 Operand<br>CMPP3 len.rw, src1addr.ab, src2addr.ab,<br>{R0-3.wl}  | 1                      |
| 5. | Compare Packed 4 Operand<br>CMPP4 src1len.rw, src1addr.ab, src2len.rw,<br>src2addr.ab, {R0-3.wl}                          | 1                      |
| 6. | Convert Long to Packed<br>CVTLP src.rl, dstlen.rw, dstaddr.ab,<br>{R0-3.wl}   | 1                      |
| 7. | Convert Packed to Long<br>CVTPL srclen.rw, srcaddr.ab, {R0-3.wl},<br>dst.wl   | 1                      |
| 8. | Convert Packed to Leading Separate<br>CVTPS srclen.rw, srcaddr.ab, dstlen.rw,<br>dstaddr.ab, {R0-3.wl}                    | 1                      |

|     | Description and Opcode  | Number of Instructions |
|-----|---|------------------------|
| 9.  | Convert Packed to Trailing<br>CVTPT srclen.rw, srcaddr.ab, tbladdr.ab,<br>dstlen.rw, dstaddr.ab, {R0-3.wl}                        | 1                      |
| 10. | Convert Leading Separate to Packed<br>CVTSP srclen.rw, srcaddr.ab, dstlen.rw,<br>dstaddr.ab, {R0-3.wl}                            | 1                      |
| 11. | Convert Trailing to Packed<br>CVTTP srclen.rw, srcaddr.ab, tbladdr.ab,<br>dstlen.rw, dstaddr.ab, {R0-3.wl}                        | 1                      |
| 12. | Divide Packed<br>DIVP divrlen.rw, divraddr.ab, divdlen.rw,<br>divdaddr.ab, quolen.rw, quoaddr.ab,<br>{R0-5.wl, -16(SP):-1(SP).wb} | 1                      |
| 13. | Move Packed<br>MOVP len.rw, srcaddr.ab, dstaddr.ab,<br>{R0-3.wl}  | 1                      |
| 14. | Multiply Packed<br>MULP mulrlen.rw, mulraddr.ab, muldlen.rw,<br>muldaddr.ab, prodlen.rw, prodaddr.ab,<br>{R0-5.wl}                | 1                      |
| 15. | Subtract Packed 4 Operand<br>SUBP4 sublen.rw, subaddr.ab, diflen.rw,<br>difaddr.ab, {R0-3.wl}                                     | 1                      |
| 16. | Subtract Packed 6 Operand<br>SUBP6 sublen.rw, subaddr.ab, minlen.rw,<br>minaddr.ab, diflen.rw, difaddr.ab,<br>{R0-5.wl}           | 1                      |

## ADDP

Add Packed

### Format

opcode    addlen.rw, addaddr.ab, sumlen.rw,  
            sumaddr.ab

opcode    add1len.rw, add1addr.ab, add2len.rw,  
            add2addr.ab, sumlen.rw, sumaddr.ab

### Condition Codes

N    <—    {sum string} LSS 0;  
Z    <—    {sum string} EQL 0;  
V    <—    {decimal overflow};  
C    <—    0;

### Exceptions

reserved operand  
decimal overflow

### Opcodes

|    |       |                      |
|----|-------|----------------------|
| 20 | ADDP4 | Add Packed 4 Operand |
| 21 | ADDP6 | Add Packed 6 Operand |

### Description

In 4 operand format, the addend string specified by the addend length and addend address operands is added to the sum string specified by the sum length and sum address operands, and the sum string is replaced by the result.

In 6 operand format, the addend1 string specified by the addend1 length and addend1 address operands is added to the addend2 string specified by the addend2 length and addend2 address operands. The sum string specified by the sum length and sum address operands is replaced by the result.

#### Notes

1. After execution of ADDP4:

R0 = 0  
R1 = Address of the byte containing the most significant digit of the  
addend string  
R2 = 0  
R3 = Address of the byte containing the most significant digit of the sum  
string

2. After execution of ADDP6:
  - R0 = 0
  - R1 = Address of the byte containing the most significant digit of the addend1 string
  - R2 = 0
  - R3 = Address of the byte containing the most significant digit of the addend2 string
  - R4 = 0
  - R5 = Address of the byte containing the most significant digit of the sum string
3. The sum string, R0 to R3 (or R0 to R5 for ADDP6) and the condition codes are UNPREDICTABLE if: the sum string overlaps the addend, addend1, or addend2 strings; the addend, addend1, addend2, or sum (4 operand only) strings contain an invalid nibble; or a reserved operand abort occurs.

## ASHP

Arithmetic Shift and Round Packed

### Format

opcode    cnt.rb, srclen.rw, srcaddr.ab, round.rb,  
          dstlen.rw, dstaddr.ab

### Condition Codes

N    <—    {dst string} LSS 0;  
Z    <—    {dst string} EQL 0;  
V    <—    {decimal overflow};  
C    <—    0;

### Exceptions

reserved operand  
decimal overflow

### Opcodes

F8        ASHP                    Arithmetic Shift and Round Packed

### Description

The source string specified by the source length and source address operands is scaled by a power of 10 specified by the count operand. The destination string specified by the destination length and destination address operands is replaced by the result.

A positive count operand effectively multiplies, a negative count effectively divides, and a zero count just moves and affects condition codes. When a negative count is specified, the result is rounded using the round operand.

#### Notes

1. After execution:  
R0 = 0  
R1 = Address of the byte containing the most significant digit of the source string  
R2 = 0  
R3 = Address of the byte containing the most significant digit of the destination string
2. The destination string, R0 to R3, and the condition codes are UNPREDICTABLE if the destination string overlaps the source string, the source string contains an invalid nibble, or a reserved operand abort occurs.
3. When the count operand is negative, the result is rounded by decimally adding bits 3:0 of the round operand to the most significant low-order digit discarded and propagating the carry, if any, to higher-order digits. Both the

source operand and the round operand are considered to be quantities of the same sign for the purpose of this addition.

4. If bits 7:4 of the round operand are nonzero, or if bits 3:0 of the round operand contain an invalid packed decimal digit, the result is UNPREDICTABLE.
5. When the count operand is zero or positive, the round operand has no effect on the result except as specified in note 4.
6. The round operand is normally 5. Truncation can be accomplished by using a zero round operand.

## CMPP

Compare Packed

### Format

3operand: opcode len.rw, src1addr.ab,  
src2addr.ab  
4operand: opcode src1len.rw, src1addr.ab,  
src2len.rw, src2addr.ab

### Condition Codes

N ← {src1 string} LSS {src2 string};  
Z ← {src1 string} EQL {src2 string};  
V ← 0;  
C ← 0;

### Exceptions

reserved operand

### Opcodes

|    |       |                          |
|----|-------|--------------------------|
| 35 | CMPP3 | Compare Packed 3 Operand |
| 37 | CMPP4 | Compare Packed 4 Operand |

### Description

In 3 operand format, the source 1 string specified by the length and source 1 address operands is compared to the source 2 string specified by the length and source 2 address operands. The only action is to affect the condition codes.

In 4 operand format, the source 1 string specified by the source 1 length and source 1 address operands is compared to the source 2 string specified by the source 2 length and source 2 address operands. The only action is to affect the condition codes.

#### Notes

- After execution of CMPP3 or CMPP4:  
R0 = 0  
R1 = Address of the byte containing the most significant digit of string1  
R2 = 0  
R3 = Address of the byte containing the most significant digit of string2
- R0 to R3 and the condition codes are UNPREDICTABLE if the source strings overlap, if either string contains an invalid nibble, or if a reserved operand abort occurs.

---

## CVTLP

Convert Long to Packed

### Format

opcode    src.rl, dstlen.rw, dstaddr.ab

### Condition Codes

N    <—    {dst string} LSS 0;  
 Z    <—    {dst string} EQL 0;  
 V    <—    {decimal overflow};  
 C    <—    0;

### Exceptions

reserved operand  
 decimal overflow

### Opcodes

F9        CVTLP                    Convert Long to Packed

### Description

The source operand is converted to a packed decimal string. The destination string operand specified by the destination length and destination address operands is replaced by the result.

#### Notes

1. After execution:
  - R0 =    0
  - R1 =    0
  - R2 =    0
  - R3 =    Address of the byte containing the most significant digit of the destination string
2. The destination string, R0 to R3, and the condition codes are UNPREDICTABLE on a reserved operand abort.
3. Overlapping operands produce correct results.

## CVTPL

Convert Packed to Long

### Format

opcode    srclen.rw, srcaddr.ab, dst.wl

### Condition Codes

N    <—    dst LSS 0;  
Z    <—    dst EQL 0;  
V    <—    {integer overflow};  
C    <—    0;

### Exceptions

reserved operand  
integer overflow

### Opcodes

36        CVTPL                    Convert Packed to Long

### Description

The source string specified by the source length and source address operands is converted to a longword, and the destination operand is replaced by the result.

#### Notes

1. After execution:  
R0 = 0  
R1 = Address of the byte containing the most significant digit of the source string  
R2 = 0  
R3 = 0
2. The destination operand, R0 to R3, and the condition codes are UNPREDICTABLE on a reserved operand abort, or if the string contains an invalid nibble.
3. The destination operand is stored after the registers are updated as specified in note 1. You may use R0 to R3 as the destination operand.
4. If the source string has a value outside the range -2,147,483,648 to +2,147,483,647, integer overflow occurs and the destination operand is replaced by the low-order 32 bits of the correctly signed infinite precision conversion. On overflow, the sign of the destination may be different from the sign of the source.
5. Overlapping operands produce correct results.

---

## CVTPS

Convert Packed to Leading Separate Numeric

### Format

opcode    srclen.rw, srcaddr.ab, dstlen.rw, dstaddr.ab

### Condition Codes

N    <—    {src string} LSS 0;  
 Z    <—    {src string} EQL 0;  
 V    <—    {decimal overflow};  
 C    <—    0;

### Exceptions

reserved operand  
 decimal overflow

### Opcodes

08        CVTPS                    Convert Packed to Leading Separate Numeric

### Description

The source packed decimal string specified by the source length and source address operands is converted to a leading separate numeric string. The destination string specified by the destination length and destination address operands is replaced by the result.

Conversion is effected by replacing the lowest-addressed byte of the destination string with the ASCII character “+” or “-”, determined by the sign of the source string. The remaining bytes of the destination string are replaced by the ASCII representations of the values of the corresponding packed decimal digits of the source string.

#### Notes

- After execution:
  - R0 =    0
  - R1 =    Address of the byte containing the most significant digit of the source string
  - R2 =    0
  - R3 =    Address of the sign byte of the destination string
- The destination string, R0 to R3, and the condition codes are UNPREDICTABLE if the destination string overlaps the source string, the source string contains an invalid nibble, or a reserved operand abort occurs.

## VAX Instruction Set

### CVTPS

3. This instruction produces an ASCII “+” or “-” in the sign byte of the destination string.
4. If decimal overflow occurs, the value stored in the destination might be different from the value indicated by the condition codes (Z and N bits).
5. If the conversion produces a -0 without overflow, the destination leading separate numeric string is changed to a +0 representation.

## CVTPT

Convert Packed to Trailing Numeric

### Format

opcode    srclen.rw, srcaddr.ab, tbladdr.ab, dstlen.rw,  
          dstaddr.ab

### Condition Codes

N    <—    {src string} LSS 0;  
Z    <—    {src string} EQL 0;  
V    <—    {decimal overflow};  
C    <—    0;

### Exceptions

reserved operand  
decimal overflow

### Opcodes

24        CVTPT                    Convert Packed to Trailing Numeric

### Description

The source packed decimal string specified by the source length and source address operands is converted to a trailing numeric string. The destination string specified by the destination length and destination address operands is replaced by the result. The condition code N and Z bits are affected by the value of the source packed decimal string.

Conversion is effected by using the highest-addressed byte of the source string (the byte containing the sign and the least significant digit), even if the source string value is -0. The assembler uses this byte as an unsigned index into a 256-byte table whose first entry (entry number 0) address is specified by the table address operand. The byte read from the table replaces the least significant byte of the destination string. The remaining bytes of the destination string are replaced by the ASCII representations of the values of the corresponding packed decimal digits of the source string.

#### Notes

- After execution:
  - R0 =    0
  - R1 =    Address of the byte containing the most significant digit of the source string
  - R2 =    0
  - R3 =    Address of the most significant digit of the destination string

## VAX Instruction Set

### CVTPT

2. The destination string, R0 to R3, and the condition codes are UNPREDICTABLE if the destination string overlaps the source string or the table; if the source string or the table contains an invalid nibble; or if a reserved operand abort occurs.
3. The condition codes are computed on the value of the source string even if overflow results. In particular, condition code N is set only if the source is nonzero and contains a minus sign (-).
4. By appropriate specification of the table, you can convert any form of trailing numeric string. See Chapter 8 for the preferred form of trailing overpunch, zoned and unsigned data. In addition, the table can be set up for absolute value, negative absolute value, or negated conversions. The translation table may be referenced even if the length of the destination string is zero.
5. Decimal overflow occurs if the destination string is too short to contain the converted result of a nonzero packed decimal source string (not including leading zeros). Conversion of a source string with zero value never results in overflow; conversion of a nonzero source string to a zero-length destination string results in overflow.
6. If decimal overflow occurs, the value stored in the destination may be different from the value indicated by the condition codes (Z and N bits).

---

## CVTSP

Convert Leading Separate Numeric to Packed

### Format

opcode    srclen.rw, srcaddr.ab, dstlen.rw, dstaddr.ab

### Condition Codes

N    <—    {dst string} LSS 0;  
 Z    <—    {dst string} EQL 0;  
 V    <—    {decimal overflow};  
 C    <—    0;

### Exceptions

reserved operand  
 decimal overflow

### Opcodes

09        CVTSP                    Convert Leading Separate Numeric to Packed

### Description

The source numeric string specified by the source length and source address operands is converted to a packed decimal string, and the destination string specified by the destination address and destination length operands is replaced by the result.

#### Notes

1. A reserved operand abort occurs if:
  - The length of the source leading separate numeric string is outside the range 0 to 31
  - The length of the destination packed decimal string is outside the range 0 to 31
  - The source string contains an invalid byte. An invalid byte is any character other than an ASCII "0" to "9" in a digit byte or an ASCII "+", "<space>", or "-" in the sign byte
2. After execution:
  - R0 =    0
  - R1 =    Address of the sign byte of the source string
  - R2 =    0
  - R3 =    Address of the byte containing the most significant digit of the destination string

## VAX Instruction Set

### CVTSP

3. The destination string, R0 to R3, and the condition codes are UNPREDICTABLE if the destination string overlaps the source string, or if a reserved operand abort occurs.
4. **srclen** is the length of the passed string minus the sign byte.

---

## CVTTP

Convert Trailing Numeric to Packed

### Format

opcode    srclen.rw, srcaddr.ab, tbladdr.ab, dstlen.rw,  
          dstaddr.ab

### Condition Codes

N    <—    {dst string}LSS 0;  
Z    <—    {dst string} EQL 0;  
V    <—    {decimal overflow};  
C    <—    0;

### Exceptions

reserved operand  
decimal overflow

### Opcodes

26        CVTTP                    Convert Trailing Numeric to Packed

### Description

The source trailing numeric string specified by the source length and source address operands is converted to a packed decimal string, and the destination packed decimal string specified by the destination address and destination length operands is replaced by the result.

Conversion is effected by using the highest-addressed (trailing) byte of the source string as an unsigned index into a 256-byte table whose first entry (entry number 0) is specified by the table address operand. The byte read from the table replaces the highest-addressed byte of the destination string (the byte containing the sign and the least significant digit). The remaining packed digits of the destination string are replaced by the low-order 4 bits of the corresponding bytes in the source string.

#### Notes

1. A reserved operand abort occurs if:
  - The length of the source trailing numeric string is outside the range 0 to 31
  - The length of the destination packed decimal string is outside the range 0 to 31
  - The source string contains an invalid byte. An invalid byte is any value other than ASCII "0" to "9" in any high-order byte (that is, any byte except the least significant byte)
  - The translation of the least significant digit produces an invalid packed decimal digit or sign nibble

## VAX Instruction Set

### CVTTP

2. After execution:
  - R0 = 0
  - R1 = Address of the most significant digit of the source string
  - R2 = 0
  - R3 = Address of the byte containing the most significant digit of the destination string
3. The destination string, R0 to R3, and the condition codes are UNPREDICTABLE if the destination string overlaps the source string or the table, or if a reserved operand abort occurs.
4. If the convert instruction produces a -0 without overflow, the destination packed decimal string is changed to a +0 representation, condition code N is cleared, and Z is set.
5. If the length of the source string is zero, the destination packed decimal string is set equal to zero, and the translation table is not referenced.
6. By appropriate specification of the table, you can convert any form of trailing numeric string. See Chapter 8 for the preferred form of trailing overpunch, zoned and unsigned data. In addition, the table can be set up for absolute value, negative absolute value, or negated conversions.
7. If the table translation produces a sign nibble containing any valid sign, the preferred sign representation is stored in the destination packed decimal string.

---

## DIVP

Divide Packed

### Format

opcode    divrlen.rw, divraddr.ab, divdlen.rw,  
          divdaddr.ab, quolen.rw, quoaddr.ab

### Condition Codes

N    <—    {quo string} LSS 0;  
Z    <—    {quo string} EQL 0;  
V    <—    {decimal overflow};  
C    <—    0;

### Exceptions

reserved operand  
decimal overflow  
divide by zero

### Opcodes

27        DIVP                    Divide Packed

### Description

The dividend string specified by the dividend length and dividend address operands is divided by the divisor string specified by the divisor length and divisor address operands. The quotient string specified by the quotient length and quotient address operands is replaced by the result.

#### Notes

1. This instruction allocates a 16-byte workspace on the stack. After execution, the stack pointer (SP) is restored to its original contents, and the contents of {(SP)-16};{(SP)-1} are UNPREDICTABLE.
2. The division is performed, resulting in the following conditions:
  - The absolute value of the remainder (which is lost) is less than the absolute value of the divisor
  - The product of the absolute value of the quotient times the absolute value of the divisor is less than or equal to the absolute value of the dividend
  - The sign of the quotient is determined by the rules of algebra from the signs of the dividend and the divisor; if the value of the quotient is zero, the sign is always positive
3. After execution:  
R0 =    0

## VAX Instruction Set

### DIVP

- R1 = Address of the byte containing the most significant digit of the divisor string
  - R2 = 0
  - R3 = Address of the byte containing the most significant digit of the dividend string
  - R4 = 0
  - R5 = Address of the byte containing the most significant digit of the quotient string
4. The quotient string, R0 to R5, and the condition codes are UNPREDICTABLE if: the quotient string overlaps the divisor or dividend strings; the divisor or dividend string contains an invalid nibble; the divisor is zero; or a reserved operand abort occurs.

## MOVP

Move Packed

### Format

opcode    len.rw, srcaddr.ab, dstaddr.ab

### Condition Codes

N    <—    {dst string} LSS 0;  
 Z    <—    {dst string} EQL 0;  
 V    <—    0;  
 C    <—    C;

### Exceptions

reserved operand

### Opcodes

34        MOVP                    Move Packed

### Description

The destination string specified by the length and destination address operands is replaced by the source string specified by the length and source address operands.

#### Notes

- After execution:
  - R0 =    0
  - R1 =    Address of the byte containing the most significant digit of the source string
  - R2 =    0
  - R3 =    Address of the byte containing the most significant digit of the destination string
- The destination string, R0 to R3, and the condition codes are UNPREDICTABLE if: the destination string overlaps the source string; the source string contains an invalid nibble; or a reserved operand abort occurs.
- If the source is -0, the result is +0, N is cleared, and Z is set.

## MULP

Multiply Packed

### Format

opcode    mulrlen.rw, mulraddr.ab, mulrlen.rw,  
          muldaddr.ab, prodlen.rw, prodaddr.ab

### Condition Codes

N    <—    {prod string} LSS 0;  
Z    <—    {prod string} EQL 0;  
V    <—    {decimal overflow};  
C    <—    0;

### Exceptions

reserved operand  
decimal overflow

### Opcodes

25        MULP                    Multiply Packed

### Description

The multiplicand string specified by the multiplicand length and multiplicand address operands is multiplied by the multiplier string specified by the multiplier length and multiplier address operands. The product string specified by the product length and product address operands is replaced by the result.

#### Notes

1. After execution:
  - R0 = 0
  - R1 = Address of the byte containing the most significant digit of the multiplier string
  - R2 = 0
  - R3 = Address of the byte containing the most significant digit of the multiplicand string
  - R4 = 0
  - R5 = Address of the byte containing the most significant digit of the product string
2. The product string, R0 to R5, and the condition codes are UNPREDICTABLE if: the product string overlaps the multiplier or multiplicand strings; the multiplier or multiplicand strings contain an invalid nibble; or a reserved operand abort occurs.

## SUBP

Subtract Packed

### Format

4operand: opcode sublen.rw, subaddr.ab,  
diflen.rw, difaddr.ab

6operand: opcode sublen.rw, subaddr.ab,  
minlen.rw, minaddr.ab,  
diflen.rw, difaddr.ab

### Condition Codes

N ← {dif string} LSS 0;  
Z ← {dif string} EQL 0;  
V ← {decimal overflow};  
C ← 0;

### Exceptions

reserved operand  
decimal overflow

### Opcodes

|    |       |                           |
|----|-------|---------------------------|
| 22 | SUBP4 | Subtract Packed 4 Operand |
| 23 | SUBP6 | Subtract Packed 6 Operand |

### Description

In 4 operand format, the subtrahend string specified by the subtrahend length and subtrahend address operands is subtracted from the difference string specified by the difference length and difference address operands, and the difference string is replaced by the result.

In 6 operand format, the subtrahend string specified by the subtrahend length and subtrahend address operands is subtracted from the minuend string specified by the minuend length and minuend address operands. The difference string specified by the difference length and difference address operands is replaced by the result.

#### Notes

- After execution of SUBP4:
  - R0 = 0
  - R1 = Address of the byte containing the most significant digit of the subtrahend string
  - R2 = 0

## VAX Instruction Set

### SUBP

R3 = Address of the byte containing the most significant digit of the difference string

2. After execution of SUBP6:

R0 = 0

R1 = Address of the byte containing the most significant digit of the subtrahend string

R2 = 0

R3 = Address of the byte containing the most significant digit of the minuend string

R4 = 0

R5 = Address of the byte containing the most significant digit of the difference string

3. The difference string, R0 to R3 (R0 to R5 for SUBP6), and the condition codes are UNPREDICTABLE if: the difference string overlaps the subtrahend or minuend strings; the subtrahend, minuend, or difference (4 operand only) strings contain an invalid nibble; or a reserved operand abort occurs.

### 9.2.12 The EDITPC Instruction and Its Pattern Operators

The EDITPC instruction implements the common editing functions that occur when handling fixed-format output. The operation consists of converting an input packed decimal number to an output character string and generating characters for the output. When converting digits, options include filling in leading zeros, protecting leading zeros, insertion of floating sign, insertion of floating currency symbol, insertion of special sign representations, and blanking an entire field when it is zero. An example of this operation is a MOVE to a numeric edited (PICTURE) item in COBOL or PL/I. Many other applications are possible.

The operands to the EDITPC instruction are as follows:

1. A **packed decimal string descriptor** (as input). This is a standard VAX operand pair consisting of the length of the decimal string in digits (up to 31) and the starting address of the string.
2. A **pattern** specification, consisting of the starting address of a pattern operation editing sequence. VAX MACRO interprets a pattern specification in the same way as it interprets normal instructions.
3. The **starting address of the output string**. The output string is described by its starting address only, because the pattern defines the length unambiguously.

The EDITPC instruction manipulates two character registers and the four condition codes:

The **fill register** (R2<7:0>) contains the fill character. This is normally an ASCII blank but could be changed to an asterisk (\*), for instance, for check protection.

The **sign register** (R2<15:8>) contains the sign character. Initially this register contains either an ASCII blank or a minus sign (-), depending upon the sign of the input. You can change the contents of this register to allow other sign representations such as plus/minus or plus/blank. You can also manipulate it to output special notations such as CR or DB. To implement a floating currency sign, you can change the sign register to the currency sign.

After execution, the condition codes describe the following:

|   |                                    |
|---|------------------------------------|
| N | The sign of the input              |
| Z | The presence of a zero source      |
| V | An overflow condition              |
| C | The presence of significant digits |

Condition code N is determined at the start of the instruction and remains unchanged (except for correcting a -0 input). The processor computes and updates the other condition codes as the instruction proceeds.

When the EDITPC instruction completes processing, registers R0 to R5 contain the values they would normally have after a decimal instruction.

## EDITPC

Edit Packed to Character String

### Format

opcode    srclen.rw, srcaddr.ab, pattern.ab, dstaddr.ab

### Condition Codes

N    <—    {src string} LSS 0; !N <- 0 if src is -0  
Z    <—    {src string} EQL 0;  
V    <—    {decimal overflow}; !nonzero digits lost  
C    <—    {significance};

### Exceptions

reserved operand  
decimal overflow

### Opcodes

38        EDITPC                    Edit Packed to Character String

### Description

The destination string specified by the pattern and destination address operands is replaced by the edited version of the source string specified by the source length and source address operands. The editing is performed according to the pattern string, starting at the address of the pattern operand and extending until a pattern end pattern operator (EO\$END) is encountered.

The pattern string consists of 1-byte pattern operators. Some pattern operators take no operands. Some take a repeat count that is contained in the rightmost nibble of the pattern operator itself. The rest take a 1-byte operand that immediately follows the pattern operator. This operand is either an unsigned integer length or a byte character.

Table 9-1 lists the pattern operators that can be used with the EDITPC instruction to form a pattern. Subsequent pages define each pattern operator in a format similar to that of the normal instruction descriptions. In each case, if there is an operand, it is either a repeat count (r) from 1 to 15, an unsigned byte length (len), or a character byte (ch). The encoding of the pattern operators is represented graphically in Table 9-2.

See Appendix E for information about exceptions that affect the EDITPC instruction.

### Notes

1. A reserved operand abort occurs if **srclen** GTRU 31.
2. The destination string is UNPREDICTABLE if any of the following is true:
  - The source string contains an invalid nibble.
  - The EO\$ADJUST\_INPUT operand is outside the range 1 to 31.

- The source and destination strings overlap.
  - The pattern and destination strings overlap.
3. After execution, the following general registers have contents as specified:
- R0 = Length of source string  
R1 = Address of the byte containing the most significant digit of the source string  
R2 = 0  
R3 = Address of the byte containing the EO\$END pattern operator  
R4 = 0  
R5 = Address of 1 byte beyond the last byte of the destination string
- If the destination string is UNPREDICTABLE, R0 to R5 and the condition codes are UNPREDICTABLE.
4. If V is set at the end and DV is enabled, a numeric overflow trap occurs unless the conditions in note 9 are satisfied.
  5. The destination length is specified exactly by the pattern operators in the pattern string. If the pattern is incorrectly formed or if it is modified during the execution of the instruction, the length of the destination string is UNPREDICTABLE.
  6. If the source is -0, the result may be -0 unless a fixup pattern operator is included (EO\$BLANK\_ZERO or EO\$REPLACE\_SIGN).
  7. The contents of the destination string and the memory preceding it are UNPREDICTABLE if the length covered by EO\$BLANK\_ZERO or EO\$REPLACE\_SIGN is zero, or if it is outside the destination string.
  8. If more input digits are requested by the pattern than are specified, a reserved operand abort is taken with R0 = -1 and R3 = location of the pattern operator that requested the extra digit. The condition codes and other registers are as specified in note 11. This abort cannot be continued.
  9. If fewer input digits are requested by the pattern than are specified, a reserved operand abort is taken with R3 = location of EO\$END pattern operator. The condition codes and other registers are as specified in note 11. This abort cannot be continued.
  10. On an unimplemented or reserved pattern operator, a reserved operand fault is taken with R3 = location of the faulting pattern operator. The condition codes and other registers are as specified in note 11. This fault can be continued as long as the defined register state is manipulated according to the pattern operator description and the state specified as "implementation dependent" is preserved.

## VAX Instruction Set EDITPC

11. On a reserved operand exception, as specified in notes 8 to 10, FPD is set and the condition codes and registers are as follows:

|             |   |
|-------------|---|
| N =         | { <b>src</b> has minus sign}                        |
| Z =         | All source digits zero so far                       |
| V =         | Nonzero digits lost                                 |
| C =         | Significance  |
| R0<31:16> = | -(count of source zeros to supply)                  |
| R0<15:0> =  | Remaining <b>srclen</b>                             |
| R1 =        | Current source location                             |
| R2<31:16> = | Implementation dependent                            |
| R2<15:8> =  | Current contents of sign register                   |
| R2<7:0> =   | Current contents of fill register                   |
| R3 =        | Location of edit pattern operator causing exception |
| R4 =        | Implementation dependent                            |
| R5 =        | Location of next destination byte                   |

**Table 9–1 Summary of EDITPC Pattern Operators**

| Name                    | Operand | Summary                                 |
|-------------------------|---------|---|
| <b>Insert operators</b> |         |   |
| EO\$INSERT              | ch      | Insert character, fill if insignificant |
| EO\$STORE_SIGN          | —       | Insert sign                             |
| EO\$FILL                | r       | Insert fill                             |
| <b>Move operators</b>   |         |   |
| EO\$MOVE                | r       | Move digits, fill if insignificant      |
| EO\$FLOAT               | r       | Move digits, floating sign              |
| EO\$END_FLOAT           | —       | End floating sign                       |
| <b>Fixup operators</b>  |         |   |
| EO\$BLANK_ZERO          | len     | Fill backward when 0                    |
| EO\$REPLACE_SIGN        | len     | Replace with fill if -0                 |
| <b>Load operators</b>   |         |   |
| EO\$LOAD_FILL           | ch      | Load fill character                     |
| EO\$LOAD_SIGN           | ch      | Load sign character                     |
| EO\$LOAD_PLUS           | ch      | Load sign character if positive         |
| EO\$LOAD_MINUS          | ch      | Load sign character if negative         |

**Key:**

ch—One character  
r—Repeat count in the range 1 to 15  
len—Length in the range 1 to 255

(continued on next page)

Table 9–1 (Cont.) Summary of EDITPC Pattern Operators

| Name                     | Operand | Summary                 |
|--------------------------|---------|-------------------------|
| <b>Control operators</b> |         |                         |
| EO\$SET_SIGNIF           | —       | Set significance flag   |
| EO\$CLEAR_SIGNIF         | —       | Clear significance flag |
| EO\$ADJUST_INPUT         | len     | Adjust source length    |
| EO\$END                  | —       | End edit                |

**Key:**

ch—One character  
r—Repeat count in the range 1 to 15  
len—Length in the range 1 to 255

Table 9–2 EDITPC Pattern Operator Encoding

| Hex         | Symbol           | Notes                           |
|-------------|------------------|---------------------------------|
| 00          | EO\$END          | —                               |
| 01          | EO\$END_FLOAT    | —                               |
| 02          | EO\$CLEAR_SIGNIF | —                               |
| 03          | EO\$SET_SIGNIF   | —                               |
| 04          | EO\$STORE_SIGN   | —                               |
| 05 . . . 1F | —                | Reserved to Compaq              |
| 20 . . . 3F | —                | Reserved for all time           |
| 40          | EO\$LOAD_FILL    | Character is in next byte       |
| 41          | EO\$LOAD_SIGN    | Character is in next byte       |
| 42          | EO\$LOAD_PLUS    | Character is in next byte       |
| 43          | EO\$LOAD_MINUS   | Character is in next byte       |
| 44          | EO\$INSERT       | Character is in next byte       |
| 45          | EO\$BLANK_ZERO   | Unsigned length is in next byte |
| 46          | EO\$REPLACE_SIGN | Unsigned length is in next byte |
| 47          | EO\$ADJUST_INPUT | Unsigned length is in next byte |
| 48 . . . 5F | —                | Reserved to Compaq              |
| 60 . . . 7F | —                | Reserved to CSS and customers   |
| 80,90,A0    | —                | Reserved to Compaq              |
| 81 . . . 8F | EO\$FILL         | —                               |
| 91 . . . 9F | EO\$MOVE         | Repeat count is <3:0>           |
| A1 . . . AF | EO\$FLOAT        | —                               |
| B0 . . . FE | —                | Reserved to Compaq              |
| FF          | —                | Reserved for all time           |

## EO\$ADJUST\_INPUT

Adjust Input Length

### Format

opcode    pattern len

### Pattern Operators

47        EO\$ADJUST\_INPUT    Adjust Input Length

### Description

The EO\$ADJUST\_INPUT pattern operator is followed by an unsigned byte integer length in the range 1 to 31. If the source string has more digits than this length, the excess leading digits are read and discarded. If any discarded digits are nonzero, the overflow is set, significance is set, and zero is cleared. If the source string has fewer digits than this length, a counter is set of the number of leading zeros to supply. This counter is stored as a negative number in R0<31:16>.

#### Note

If the length is not in the range 1 to 31, the destination string, condition codes, and R0 to R5 are UNPREDICTABLE.

---

## EO\$BLANK\_ZERO

Blank Backwards when Zero

### Format

opcode    pattern len

### Pattern Operators

45        EO\$BLANK\_ZERO        Blank Backwards when Zero

### Description

The EO\$BLANK\_ZERO pattern operator is followed by an unsigned byte integer length. If the value of the source string is zero, then the contents of the fill register are stored into the last length bytes of the destination string.

#### Notes

1. The length must be nonzero and within the destination string already produced. If it is not, the contents of the destination string and the memory preceding it are UNPREDICTABLE.
2. Use this pattern operator to blank out any characters stored in the destination under a forced significance such as a sign or the digits following the radix point.

## EO\$END

End Edit

### Format

opcode    pattern

### Pattern Operators

00        EO\$END                    End Edit

### Description

The EO\$END pattern operator terminates the edit operation.

#### Notes

1. If there are still input digits, a reserved operand abort is taken.
2. If the source value is -0, the N condition code is cleared.

---

## EO\$END\_FLOAT

End Floating Sign

### Format

opcode    pattern

### Pattern Operators

|    |               |                   |
|----|---------------|-------------------|
| 01 | EO\$END_FLOAT | End Floating Sign |
|----|---------------|-------------------|

### Description

The EO\$END\_FLOAT pattern operator terminates a floating sign operation. If the floating sign has not yet been placed in the destination (if significance is not set), the contents of the sign register are stored in the destination, and significance is set.

#### Note

Use this pattern operator after a sequence of one or more EOSFLOAT pattern operators that start with significance clear. The EOSFLOAT sequence can include intermixed EOSINSERTs and EOSFILLs.

## EO\$FILL

Store Fill

### Format

opcode    pattern r

### Pattern Operators

8x        EO\$FILL                    Store Fill

### Description

The rightmost nibble of the pattern operator is the repeat count. The EO\$FILL pattern operator places the contents of the fill register into the destination the number of times specified by the repeat count.

#### Note

Use this pattern operator for fill (blank) insertion.

---

## EO\$FLOAT

Float Sign

### Format

opcode    pattern r

### Pattern Operators

Ax        EO\$FLOAT                      Float Sign

### Description

The EO\$FLOAT pattern operator moves digits, floating the sign across insignificant digits. The rightmost nibble of the pattern operator is the repeat count. For the number of times specified in the repeat count, the following algorithm is executed:

The next digit from the source is examined. If it is nonzero and significance is not yet set, then the contents of the sign register are stored in the destination, significance is set, and zero is cleared. If the digit is significant, it is stored in the destination; otherwise, the contents of the fill register are stored in the destination.

### Notes

1. If r is greater than the number of digits remaining in the source string, a reserved operand abort is taken.
2. Use this pattern operator to move digits with a floating arithmetic sign. The sign must already be set up as for EOSSTORE\_SIGN. A sequence of one or more EO\$FLOATs can include intermixed EO\$INSERTs and EO\$FILLs. Significance must be clear before the first pattern operator of the sequence. The sequence must be terminated by one EO\$END\_FLOAT.
3. Use this pattern operator to move digits with a floating currency sign. The sign must already be set up with an EOSLOAD\_SIGN. A sequence of one or more EO\$FLOATs can include intermixed EO\$INSERTs and EO\$FILLs. Significance must be clear before the first pattern operator of the sequence. The sequence must be terminated by one EO\$END\_FLOAT.

## EO\$INSERT

Insert Character

### Format

opcode    pattern ch

### Pattern Operators

44        EO\$INSERT                    Insert Character

### Description

The EO\$INSERT pattern operator is followed by a character. If significance is set, the character is placed into the destination. If significance is not set, the contents of the fill register are placed into the destination.

#### Note

Use this pattern operator for inserts that can be made blank (for example, comma (,)) and fixed inserts (for example, slash (/)). Fixed inserts require that significance be set (by EOSSET\_SIGNIF or EO\$END\_FLOAT).

---

**EO\$LOAD\_**

Load Register

**Format**

opcode    pattern ch

**Pattern Operators**

|    |                |                             |
|----|----------------|-----------------------------|
| 40 | EO\$LOAD_FILL  | Load Fill Register          |
| 41 | EO\$LOAD_SIGN  | Load Sign Register          |
| 42 | EO\$LOAD_PLUS  | Load Sign Register If Plus  |
| 43 | EO\$LOAD_MINUS | Load Sign Register If Minus |

**Description**

The pattern operator is followed by a character. For EO\$LOAD\_FILL, this character is placed into the fill register. For EO\$LOAD\_SIGN, this character is placed into the sign register. For EO\$LOAD\_PLUS, this character is placed into the sign register if the source string has a positive sign. For EO\$LOAD\_MINUS, this character is placed into the sign register if the source string has a negative sign.

**Notes**

1. Use EO\$LOAD\_FILL to set up check protection (\* instead of space).
2. Use EO\$LOAD\_SIGN to set up a floating currency sign.
3. Use EO\$LOAD\_PLUS to set up a nonblank plus sign.
4. Use EO\$LOAD\_MINUS to set up a nonminus minus sign (such as CR, DB, or the PL/I +).

## EO\$MOVE

Move Digits

### Format

opcode pattern r

### Pattern Operators

9x EO\$MOVE Move Digits

### Description

The EO\$MOVE pattern operator moves digits, filling for insignificant digits. The rightmost nibble of the pattern operator is the repeat count. For the number of times specified in the repeat count, the following algorithm is executed:

The next digit is moved from the source to the destination. If the digit is nonzero, significance is set and zero is cleared. If the digit is not significant (that is, a leading zero), it is replaced by the contents of the fill register in the destination.

#### Notes

1. If *r* is greater than the number of digits remaining in the source string, a reserved operand abort is taken.
2. Use this pattern operator to move digits without a floating sign. If leading-zero suppression is desired, significance must be clear. If leading zeros should be explicit, significance must be set. A string of EO\$MOVEs intermixed with EO\$INSERTs and EO\$FILLs will handle suppression correctly.
3. If check protection (\*) is desired, EO\$LOAD\_FILL must precede the EO\$MOVE.

---

## EO\$REPLACE\_SIGN

Replace Sign when Zero

### Format

opcode    pattern len

### Pattern Operators

46        EO\$REPLACE\_SIGN    Replace Sign when Zero

### Description

The EO\$REPLACE\_SIGN pattern operator is followed by an unsigned byte integer length. If the value of the source string is zero (that is, if Z is set), the contents of the fill register are stored in the byte of the destination string that is **len** bytes before the current position.

#### Notes

1. The length must be nonzero and within the destination string already produced. If it is not, the contents of the destination string and the memory preceding it are UNPREDICTABLE.
2. You can use this pattern operator to correct a stored sign (EO\$END\_FLOAT or EO\$STORE\_SIGN) if a minus was stored and the source value turned out to be zero.

## EO\$\_SIGNIF

Significance

### Format

opcode    pattern

### Pattern Operators

|    |                  |                    |
|----|------------------|--------------------|
| 02 | EO\$CLEAR_SIGNIF | Clear Significance |
| 03 | EO\$SET_SIGNIF   | Set Significance   |

### Description

The significance indicator is set or cleared. This controls the treatment of leading zeros (leading zeros are zero digits for which the significance indicator is clear).

#### Notes

1. Use EO\$CLEAR\_SIGNIF to initialize leading-zero suppression (EO\$MOVE) or floating sign (EO\$FLOAT) following a fixed insert (EO\$INSERT with significance set).
2. Use EO\$SET\_SIGNIF to avoid leading-zero suppression (before EO\$MOVE) or to force a fixed insert (before EO\$INSERT).

---

## EO\$STORE\_SIGN

Store Sign

### Format

opcode    pattern

### Pattern Operators

|    |                |            |
|----|----------------|------------|
| 04 | EO\$STORE_SIGN | Store Sign |
|----|----------------|------------|

### Description

The EO\$STORE\_SIGN pattern operator places contents of the sign register into the destination.

#### Note

Use this pattern operator for any nonfloating arithmetic sign. Precede it with either a EO\$LOAD\_PLUS or EO\$LOAD\_MINUS, or both, if the default sign convention is not desired.

## VAX Instruction Set

### EO\$STORE\_SIGN

#### 9.2.13 Other VAX Instructions

The following table lists other VAX instructions:

|    | Description and Opcode   | Number of Instructions |
|----|--|------------------------|
| 1. | Probe {Read, Write} Accessibility<br>PROBE{R,W} mode.rb, len.rw, base.ab   | 2                      |
| 2. | Change Mode<br>CHM{K,E,S,U} param.rw, {-(ySP).w*}<br>Where $y = \text{MINU}(x, \text{PSL} \langle \text{current\_mode} \rangle)$ | 4                      |
| 3. | Return from Exception or Interrupt<br>REI {(SP)+.r*}   | 1                      |
| 4. | Load Process Context<br>LDPCTX {PCB.r*, -(KSP).w*}   | 1                      |
| 5. | Save Process Context<br>SVPCTX {(SP)+.r*, PCB.w*}  | 1                      |
| 6. | Move to Process Register<br>MTPR src.rl, procreg.rl  | 1                      |
| 7. | Move from Processor Register<br>MFPR procreg.rl, dst.wl  | 1                      |
| 8. | Bugcheck with {word, longword} message identifier<br>BUG{W,L} message.bx   | 2                      |

## PROBEx

Probe Accessibility

### Format

opcode    mode.rb, len.rw, base.ab

### Condition Codes

N    <—    0;  
 Z    <—    if {both accessible} then 0 else 1;  
 V    <—    0;  
 C    <—    C;

### Exceptions

translation not valid

### Opcodes

|    |        |                           |
|----|--------|---------------------------|
| 0C | PROBER | Probe Read Accessibility  |
| 0D | PROBEW | Probe Write Accessibility |

### Description

The PROBE instruction checks the read or write accessibility of the first and last byte specified by the base address and the zero-extended length. Note that the bytes in between are not checked. System software must check all pages if they will be accessed between the two end bytes.

The protection is checked against the larger (and therefore less privileged) of the modes specified in bits <1:0> of the mode operand and the previous mode field of the processor status longword (PSL). Note that probing with a mode operand of zero is equivalent to probing the mode specified in the previous-mode field of the PSL.

## VAX Instruction Set

### PROBE<sub>x</sub>

#### Example

```
MOVL    4(AP),R0        ; Copy the address of first arg so
                        ; that it cannot be changed
PROBER  #0,#4,(R0)      ; Verify that the longword pointed to
                        ; by the first arg could be read by
                        ; the previous access mode
                        ; Note that the arg list itself must
                        ; already have been probed
BEQL    violation       ; Branch if either byte gives an
                        ; access violation
MOVQ    8(AP),R0        ; Copy length and address of buffer
                        ; arg so that they cannot change
PROBER  #0,R0,(R1)      ; Verify that the buffer described by
                        ; the 2nd and 3rd args could be
                        ; written by the previous access
                        ; mode
                        ; Note that the arg list must already
                        ; have been probed and that the 2nd
                        ; arg must be known to be less than
                        ; 512
BEQL    violation       ; Branch if either byte gives an
                        ; access violation
```

Note that for the PROBE instruction, probing an address returns only the accessibility of the pages and has no effect on their residency. However, probing a process address may cause a page fault in the system address space on the per-process page tables.

#### Notes

1. If the valid bit of the examined page table entry is set, it is UNPREDICTABLE whether the modify bit of the examined page table entry is set by a PROBER. If the valid bit is clear, the modify bit is not changed.
2. Except for note 1, above, the valid bit of the page table entry, PTE<31>, mapping the probed address is ignored.
3. A length violation gives a status of “not-accessible.”
4. On the probe of a process virtual address, if the valid bit of the system page table entry is zero, a Translation Not Valid Fault occurs. This allows for the demand paging of the process page tables.
5. On the probe of a process virtual address, if the protection field of the system page table entry indicates No Access, a status of “not-accessible” is given. Thus, a single No Access page table entry in the system map is equivalent to 128 No Access page table entries in the process map.

## CHM

Change Mode

### Format

opcode code.rw

### Condition Codes

N ← 0;  
Z ← 0;  
V ← 0;  
C ← 0;

### Exceptions

halt

### Opcodes

|    |      |                           |
|----|------|---------------------------|
| BC | CHMK | Change Mode to Kernel     |
| BD | CHME | Change Mode to Executive  |
| BE | CHMS | Change Mode to Supervisor |
| BF | CHMU | Change Mode to User       |

### Description

Change mode instructions allow processes to change their access mode in a controlled manner. The instruction increases privilege only (decreases the access mode).

A change in mode also results in a change of stack pointers; the old pointer is saved, and the new pointer is loaded. The processor status longword (PSL), program counter (PC), and code passed by the instruction are pushed onto the stack of the new mode. The saved PC addresses the instruction following the CHM<sub>x</sub> instruction. The code is sign extended. After execution, the appearance of the new stack is as follows:

|                        |        |
|------------------------|--------|
| Sign-Extended Code     | : (SP) |
| PC of next instruction |        |
| Old PSL                |        |

ZK-1177A-GE

The destination mode selected by the opcode is used to obtain a location from the system control block (SCB). This location addresses the CHM<sub>x</sub> dispatcher for the specified mode. If the vector<1:0> code is NEQU 0, then the operation is UNDEFINED.

## VAX Instruction Set

### CHM

#### Notes

1. As usual for faults, any Access Violation or Translation Not Valid fault saves the PC and the PSL, and leaves the stack pointer (SP) as it was at the beginning of the instruction except for any pushes onto the kernel stack. Note that addresses just off the top of the target stack may have been written.
2. The noninterrupt stack pointers may be fetched and stored either in privileged registers or in their allocated slots in the process control block (PCB). Only LDPCTX and SVPCTX always fetch and store in the PCB. MFPR and MTPR always fetch and store the pointers whether in registers or the PCB.
3. By software convention, negative codes are reserved to CSS and customers.

#### Examples

1. CHMK #7 ; Request the kernel mode service  
; specified by code 7
- CHME #4 ; Request the executive mode service  
; specified by code 4
- CHMS #-2 ; Request the supervisor mode service  
; specified by customer code -2

---

## REI

Return from Exception or Interrupt

### Format

opcode

### Condition Codes

N ← saved PSL<3>;  
 Z ← saved PSL<2>;  
 V ← saved PSL<1>;  
 C ← saved PSL<0>;

### Exceptions

reserved operand

### Opcodes

02 REI Return from Exception or Interrupt

### Description

A longword is popped from the current stack and held in a temporary program counter (PC). A second longword is popped from the current stack and held in a temporary processor status longword (PSL).

The popped PSL is checked for internal consistency. If the processor is running virtual machine (VM) mode, the popped PSL is compared with the Virtual-Machine Processor Status Longword (VMPSL) to determine that the transition from current VMPSL to popped PSL is allowed, and a VM-emulation trap is taken. If the processor is running a real machine, the popped PSL is compared with the current PSL to determine that the transition from current PSL to popped PSL is allowed.

If the processor is not in kernel mode and is attempting to return to a PSL with the VMPSL VM bit set, a reserved operand fault occurs. The current stack pointer (SP) is saved, and a new SP is selected according to the new PSL CUR\_MOD and IS fields. The level of the highest privilege asynchronous system trap (AST) is checked against the current mode to see whether a pending AST can be delivered. Execution resumes with the instruction being executed at the time of the exception or interrupt.

After completing an REI, a processor will correctly execute a modified instruction stream.

### Notes

1. The exception or interrupt service routine is responsible for restoring any registers saved and for removing any parameters from the stack.
2. As usual for faults, any Access Violation or Translation Not Valid conditions on the stack pops restore the stack pointer and fault.

## VAX Instruction Set

### REI

3. The noninterrupt stack pointers may be fetched and stored either in privileged registers or in their allocated slots in the process control block (PCB). Only LDPCTX and SVPCTX always fetch and store in the PCB. MFPR and MTPR always fetch and store the pointers, whether in registers or in the PCB.

---

## LDPCTX

Load Process Context

### Format

opcode

### Condition Codes

N ← N;  
Z ← Z;  
V ← V;  
C ← C;

### Exceptions

reserved operand  
privileged instruction

### Opcodes

|    |        |                      |
|----|--------|----------------------|
| 06 | LDPCTX | Load Process Context |
|----|--------|----------------------|

### Description

If the processor is in virtual machine (VM) mode, and the virtual machine is in kernel mode, then a VM-emulation trap is taken. Otherwise, if the processor is not in kernel mode, a privileged-instruction fault is taken. If neither exception is taken, the processor loads the process state in the process control block (PCB) specified by the privileged process control block base register (PCBB).

The general registers, process-space memory management registers, and the address space number register (if implemented) are loaded from the PCB into the scalar processor. Execution is switched to the kernel stack. The program counter (PC) and processor status longword (PSL) are moved from the PCB to the stack, suitable for use by a subsequent REI instruction.

If the processor implements an address space number (ASN) register, the process translation buffer (TB) state associated with the new value of the ASN (that is, the one loaded by the LDPCTX instruction) is flushed if the process last ran on a different processor. This is indicated by the previous CPU (PRVCPU) field being not equal to the CPU identification (CUID) register. If the processor does not implement the ASN register, the process-space TB state is unconditionally flushed.

### Notes

1. Some processors keep a copy of each of the per-process stack pointers (SPs) in internal registers. In those processors, LDPCTX loads the internal registers from the PCB. Processors that do not keep a copy of all four per-process stack pointers in internal registers keep only the current access mode register in an internal register and switch this with the PCB contents whenever the current access mode field changes.

## VAX Instruction Set

### LDPCTX

2. The preferred implementation of UNDEFINED operation is reserved operand abort.
3. LDPCTX does not invalidate the per-process translation buffer (TB) state in the vector processor TB. To invalidate the TB state on the vector processor use the invalidate all (TBIA), invalidate single (TBIS), or vector invalidate all (VTBIA) internal processor registers.
4. LDPCTX does not load the vector processor memory management registers, if such copies reside there.
5. To guarantee correct operation, an LDPCTX instruction must be followed by an REI instruction.

---

## SVPCTX

Save Process Context

### Format

opcode

### Condition Codes

|   |    |    |
|---|----|----|
| N | <— | N; |
| Z | <— | Z; |
| V | <— | V; |
| C | <— | C; |

### Exceptions

privileged instruction

### Opcodes

|    |        |                      |
|----|--------|----------------------|
| 07 | SVPCTX | Save Process Context |
|----|--------|----------------------|

### Description

If the processor is in virtual machine (VM) mode, and the virtual machine is in kernel mode, then a VM-emulation trap is taken. Otherwise, the process control block (PCB) is specified by the privileged process control block base register (PCBB). The general registers are saved into the PCB. The program counter (PC) and processor status longword (PSL) currently on the top of the current stack are popped and stored in the PCB. If the processor implements the address space number (ASN) register, then the CPU identification (CPUID) register is saved in the previous CPU (PRVCP) field in the PCB. If a SVPCTX instruction is executed when the interrupt stack (IS) is clear, then IS is set, the interrupt stack pointer (ISP) is activated, and interrupt priority level (IPL) is maximized with 1 because of the switch to the IS.

### Notes

1. The map, ASTLVL, and PME contents of the process control block (PCB) are not saved because they are rarely changed. Thus, not writing them saves overhead.
2. Some processors keep a copy of each of the per-process stack pointers in internal registers. In those processors, SVPCTX stores the internal registers in the PCB. Processors that do not keep a copy of all four per-process stack pointers in internal registers keep only the current access mode register in an internal register and switch this access mode register with the PCB contents whenever the current access mode field changes.
3. Between the SVPCTX instruction that saves the state for one process and the LDPCTX that loads the state of another, the ISPs may not be referenced by MFPR or MTPR instructions. This implies that interrupt service routines invoked at a priority higher than the lowest one used for context switching must not reference the process stack pointers (SPs).

## MTPR

Move to Processor Register

### Format

opcode    src.rl, procreg.rl

### Condition Codes

|   |    |               |
|---|----|---------------|
| N | <— | UNPREDICTABLE |
| Z | <— | UNPREDICTABLE |
| V | <— | UNPREDICTABLE |
| C | <— | UNPREDICTABLE |

### Exceptions

reserved operand fault  
reserved instruction fault

### Opcodes

|    |      |                            |
|----|------|----------------------------|
| DA | MTPR | Move to Processor Register |
|----|------|----------------------------|

### Description

If the processor is in virtual machine (VM) mode, and the virtual machine is in kernel mode, then a VM-emulation trap is taken. MTPR loads the source operand specified by **src** into all copies of the processor register specified by **procreg** that are implemented on the vector and scalar processors. The **procreg** operand is a longword that contains the processor register number. Execution may have register-specific side effects.

#### Notes

1. If the processor internal register does not exist, a reserved operand fault occurs.
2. A reserved instruction fault occurs if instruction execution is attempted in other than kernel mode.
3. A reserved operand fault occurs on a move to a read-only register.
4. After an MTPR instruction, the condition codes are UNPREDICTABLE, unless noted otherwise under the description of the specific processor register.

---

## MFPR

Move from Processor Register

### Format

opcode    procreg.ri, dst.wl

### Condition Codes

N    <—    UNPREDICTABLE  
Z    <—    UNPREDICTABLE  
V    <—    UNPREDICTABLE  
C    <—    UNPREDICTABLE

### Exceptions

reserved operand fault  
reserved instruction fault

### Opcodes

DB        MFPR                            Move from Processor Register

### Description

If the processor is in virtual machine (VM) mode, and the virtual machine is in kernel mode, then a VM-emulation trap is taken. The destination operand is replaced by the contents of the processor register specified by **procreg**. The **procreg** operand is a longword that contains the processor register number. Execution may have register-specific side effects.

#### Notes

1. If the processor internal register does not exist, a reserved operand fault occurs.
2. A reserved instruction fault occurs if instruction execution is attempted in other than kernel mode.
3. A reserved operand fault occurs on a move from a write-only register.
4. After an MFPR instruction, the condition codes are UNPREDICTABLE, unless noted otherwise under the description of the specific processor register.

## BUG

Bugcheck

### Format

opcode message.bx

### Condition Codes

N ← N;  
Z ← Z;  
V ← V;  
C ← C;

### Exceptions

reserved instruction

### Opcodes

|      |      |   |
|------|------|---|
| FEFF | BUGW | Bugcheck with word message identifier     |
| FDFD | BUGL | Bugcheck with longword message identifier |

### Description

The hardware treats these opcodes as reserved to Compaq and as faults. The OpenVMS operating system treats them as requests to report software detected errors. The inline message identifier is zero extended to a longword (BUGW) and interpreted as a condition value (see the VAX Procedure Calling and Condition Handling Standard in the *OpenVMS Programming Interfaces: Calling a System Routine*). If the process is privileged to report bugs, a log entry is made. If the process is not privileged, a reserved instruction is signaled.

### Examples

1. BUGW ; Bugcheck with word message  
.WORD 4 ; identifier 4  
BUGL ; Bugcheck with longword  
.LONG 5 ; message identifier 5

---

## VAX Vector Architecture

This chapter describes an extension to the VAX architecture for integrated vector processing. Some VAX vector architecture departs from the traditional VAX scalar architecture, especially in the areas of UNPREDICTABLE results, vector processor exceptions, and instruction/memory synchronization.

### 10.1 Introduction to VAX Vector Architecture

Implementation of the VAX vector architecture is optional. VAX processors that do implement the vector architecture do so as specified in this chapter. Operating system software may emulate the vector architecture on processors that omit this feature.

On VAX processors that omit the vector architecture, vector instructions result in a reserved-instruction fault.

The vector architecture features include additional instructions, vector registers, and vector control registers.

All descriptions and examples of vector instructions in this chapter use the assembler notation form of instructions, as described in Section 10.5. The number and order of operands for the assembler notation differ from that defined in the instruction stream format. See Section 10.3 and Section 10.5 for additional information.

### 10.2 VAX Vector Architecture Registers

This section identifies and describes the vector, vector control, and internal processor registers used in processing vector architecture operations.

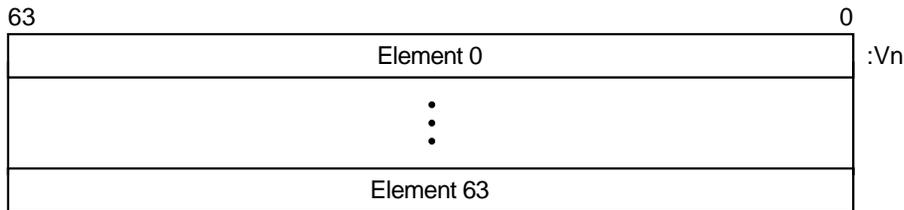
#### 10.2.1 Vector Registers

There are 16 vector registers, V0 to V15. Each vector register contains 64 elements numbered 0 to 63. Each element is 64 bits wide. Figure 10–1 depicts a vector register.

# VAX Vector Architecture

## 10.2 VAX Vector Architecture Registers

Figure 10–1 Vector Register



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A vector instruction that performs a register-to-register operation is defined as a **vector operate instruction**. A vector operate instruction that reads or writes F\_floating data, or integer data for shifts or integer arithmetic operations, reads bits <31:0> of each source element and writes bits <31:0> of each destination element. Bits <63:32> of the destination are UNPREDICTABLE for F\_floating, integer arithmetic, and shift instructions.

Vector logical instructions read bits <31:0> of each source element and write the result into bits <31:0> of each destination element; bits <63:32> of the destination element receive bits <63:32> of the corresponding element of the Vb source operand.

For vector instructions that read longword data from memory into a vector register (VLDL and VGATHL), bits <63:32> of the destination elements are UNPREDICTABLE.

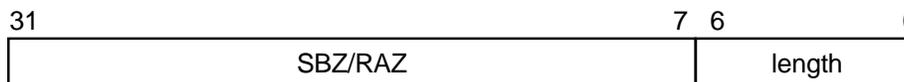
If the same vector register is used as both source and destination in a Gather Memory Data into Vector Register (VGATH) instruction, the result of the VGATH instruction is UNPREDICTABLE.

For the IOTA vector instruction, bits <63:32> of the destination elements are UNPREDICTABLE.

### 10.2.2 Vector Control Registers

The 7-bit Vector Length Register (VLR), shown in Figure 10–2, limits the highest vector element to be processed by a vector instruction. VLR is loaded prior to executing the vector instruction using a Move to Vector Processor (MTVP) instruction. The value in VLR may range from 0 to 64. If the vector length is zero, no vector elements are processed. If a vector instruction is executed with a vector length greater than 64, the results are UNPREDICTABLE. Elements beyond the vector length in the destination vector register are not modified.

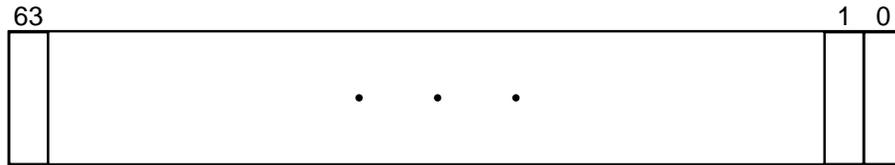
Figure 10–2 Vector Length Register (VLR)



ZK-1446A-GE

The Vector Mask Register (VMR), shown in Figure 10–3, has 64 bits, each corresponding to an element of a vector register. Bit <0> corresponds to vector element 0. See Section 10.3.1 for information on masked operations.

Figure 10–3 Vector Mask Register (VMR)



ZK-1447A-GE

The 7-bit Vector Count Register (VCR), shown in Figure 10–4, receives the length of the offset vector generated by the IOTA instruction.

Figure 10–4 Vector Count Register (VCR)



ZK-1448A-GE

These registers are read and written by Move from/to Vector Processor (MFVP/MTVP) instructions.

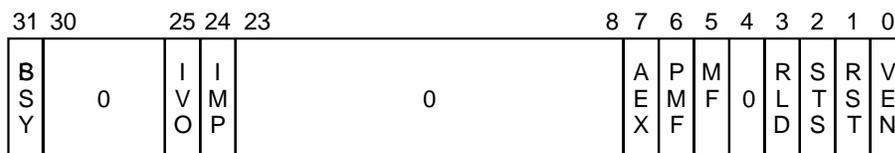
### 10.2.3 Internal Processor Registers

The vector processor contains the following internal processor registers (IPRs) that can be accessed by the scalar processor using MTPR/MFPR instructions:

- Vector Processor Status Register (VPSR)
- Vector Arithmetic Exception Register (VAER)
- Vector Memory Activity Check (VMAC)
- Vector Translation Buffer Invalidate All (VTBIA)
- Vector State Address Register (VSAR)

The VPSR is shown in Figure 10–5, and is described in Table 10–1.

Figure 10–5 Vector Processor Status Register (VPSR)



ZK-1449A-GE

## VAX Vector Architecture

### 10.2 VAX Vector Architecture Registers

**Table 10–1 Description of the Vector Processor Status Register (VPSR)**

| Extent  | Type  | Description   |
|---------|-------|---|
| <0>     | R/W   | Vector Processor Enabled (VEN). The vector processor is enabled by writing a one to this bit. Writing a zero disables the vector processor. If VPSR<VEN> is cleared by software while VPSR<BSY> is set, then once the new state of VPSR becomes synchronized with subsequent vector instructions, no more instructions are sent and the vector processor completes execution of all pending instructions in its instruction queue. See Section 10.6.3, Vector Processor Disabled, for more details. |
| <1>     | W     | Vector Processor State Reset (RST). Writing a one to this bit clears VPSR and VAER. If VPSR<RST> is set by software while VPSR<BSY> is set, the operation of the vector processor is UNDEFINED. This bit is read as zero (RAZ).   |
| <2>     | W     | Vector State Store (STS). Writing a one to this bit initiates storing of implementation-specific vector state information to memory using the address in VSAR for the asynchronous method of handling memory management exceptions. If the synchronous method is implemented, write operations to VPSR<STS> are ignored. This bit is RAZ.   |
| <3>     | W     | Vector State Reload (RLD). Writing a one to this bit initiates reloading of implementation-specific vector state information from memory using the address in VSAR for the asynchronous method of handling memory management exceptions. If the synchronous method is implemented, write operations to VPSR<RLD> are ignored. This bit is RAZ.  |
| <4>     | R     | 0   |
| <5>     | R/W1C | Memory Fault (MF). This bit is set by the vector processor when there is a memory reference to be retried due to an asynchronous memory management exception. Writing a one to VPSR<MF> clears it. Writing a zero to VPSR<MF> has no effect. If the synchronous method of handling memory management exceptions is implemented, this bit is always zero.  |
| <6>     | R/W1C | Pending Memory Fault (PMF). This bit is set by the vector processor when an asynchronous memory management exception is pending. Writing a one to VPSR<PMF> clears it. Writing a zero to VPSR<PMF> has no effect. If the synchronous method of handling memory management exceptions is implemented, this bit is always zero.   |
| <7>     | R/W1C | Vector Arithmetic Exception (AEX). This bit is set by the vector processor when disabling itself due to an arithmetic exception. Information regarding the nature of the exception can be found in VAER. Writing a one to VPSR<AEX> clears VPSR<AEX> and VAER. Writing a zero to VPSR<AEX> has no effect.   |
| <23:8>  | R     | 0   |
| <24>    | R/W1C | Implementation-Specific Hardware Error (IMP). This bit is set by the vector processor when disabling itself due to an implementation-specific hardware error. Writing a one to VPSR<IMP> clears it. Writing a zero to VPSR<IMP> has no effect.<br><br>An implementation may choose not to implement VPSR<IMP>. In this case, writing VPSR<IMP> with either value must have no effect and must not generate any error. Also, its value when read must be zero.                                       |
| <25>    | R/W1C | Illegal Vector Opcode (IVO). This bit is set by the vector processor when disabling itself due to receiving an illegal vector opcode. Writing a one to VPSR<IVO> clears it. Writing a zero to VPSR<IVO> has no effect.<br><br>An implementation may choose not to implement VPSR<IVO>. In this case, writing VPSR<IVO> with either value must have no effect and must not generate any error. Also, its value when read must be zero.   |
| <30:26> | R     | 0   |

(continued on next page)

**Table 10–1 (Cont.) Description of the Vector Processor Status Register (VPSR)**

| Extent | Type | Description   |
|--------|------|---|
| <31>   | R    | Vector Processor Busy (BSY). When this bit is set, the vector processor is executing vector instructions. When it is clear, the vector processor is idle, or the vector processor has suspended instruction execution due to an asynchronous memory management exception or hardware error. Writing to VPSR<BSY> has no effect. |

Table 10–2 shows the possible settings of VPSR<3:0> in the same MTPR instruction, and the resulting action for the vector processor. The state of the vector processor is determined by the encoding of Vector Processor Enabled (VPSR<VEN>) and Vector Processor Busy (VPSR<BSY>). The vector processor state for possible encodings is shown in Table 10–3.

**Table 10–2 Possible VPSR<3:0> Settings for MTPR**

| RLD | STS | RST | VEN | Meaning                                       |
|-----|-----|-----|-----|---|
| 0   | 0   | 0   | 0   | Disable vector processor                      |
| 0   | 0   | 0   | 1   | Enable vector processor                       |
| 0   | 0   | 1   | 0   | Reset state and disable vector processor      |
| 0   | 0   | 1   | 1   | Reset state and enable vector processor       |
| 0   | 1   | 0   | 0   | Store state (must disable vector processor)   |
| 1   | 0   | 0   | 0   | Reload state and disable vector processor     |
| 1   | 0   | 0   | 1   | Reload state and then enable vector processor |

**Table 10–3 State of the Vector Processor**

| VEN | BSY | Meaning  |
|-----|-----|--|
| 0   | 0   | The vector processor is not executing any instructions now, and either has no pending instructions or will not execute pending instructions. No more instructions should be sent.                  |
| 0   | 1   | The vector processor is executing at least one pending instruction. No more instructions should be sent.   |
| 1   | 0   | The vector processor is not executing any instructions now, and either has no pending instructions or will not execute pending instructions. New instructions can be sent to the vector processor. |
| 1   | 1   | The vector processor is executing at least one instruction now. New instructions can be sent.  |

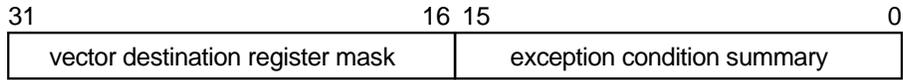
Note that because the vector and scalar processors can execute asynchronously, a VPSR state transition may not be seen immediately by the scalar processor. After performing an MTPR to VPSR, software must then issue an MFPR from VPSR to ensure that the new state of VPSR (and VAER if cleared by VPSR<RST>) will affect the execution of subsequently issued vector instructions. The MFPR in this case will not complete until the new state of the vector processor becomes visible to the scalar processor. If software does not issue the MFPR, then it is UNPREDICTABLE whether this synchronization between the new state of VPSR (and VAER) and subsequently issued vector instructions occurs.

## VAX Vector Architecture

### 10.2 VAX Vector Architecture Registers

The VAER, shown in Figure 10–6, is a read-only register used to record information regarding vector arithmetic exceptions. Table 10–4 shows the encoding for the exception condition types. The destination register mask field of VAER records which vector registers have received default results due to arithmetic exceptions. VAER<16+n> corresponds to vector register Vn, where n is between 0 and 15. For more information, refer to Section 10.6.2, Vector Arithmetic Exceptions.

**Figure 10–6 Vector Arithmetic Exception Register (VAER)**



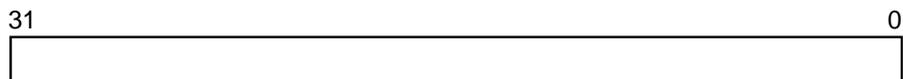
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**Table 10–4 VAER Exception Condition Summary Word Encoding**

| Bit    | Exception Condition       |
|--------|---------------------------|
| <0>    | Floating underflow        |
| <1>    | Floating divide by zero   |
| <2>    | Floating reserved operand |
| <3>    | Floating overflow         |
| <4>    | 0                         |
| <5>    | Integer overflow          |
| <15:6> | 0                         |

The Vector Memory Activity Check (VMAC) register, shown in Figure 10–7, is used to guarantee the completion of all prior vector memory accesses. For more information on this function of VMAC, refer to Section 10.7.2.2. An MFPR from VMAC also ensures that all hardware errors encountered by previous vector memory instructions are reported before the MFPR completes. For more information on this function of VMAC, refer to Section 10.9, Hardware Errors. The value returned by MFPR from VMAC is UNPREDICTABLE.

**Figure 10–7 Vector Memory Activity Check (VMAC) Register**



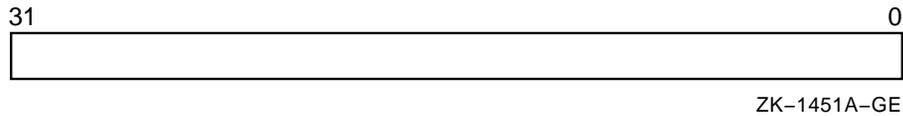
ZK-1451A-GE

The Vector Translation Buffer Invalidate All (VTBIA) register, shown in Figure 10–8, is a write-only register that may be omitted in some implementations. If the vector processor contains its own translation buffer, moving zero into VTBIA using the MTPR instruction invalidates the entire vector translation buffer. For more information, refer to Section 10.8, Memory Management.

## VAX Vector Architecture

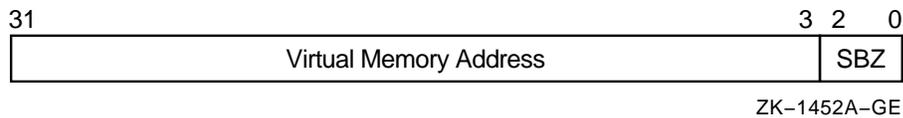
### 10.2 VAX Vector Architecture Registers

**Figure 10–8 Vector Translation Buffer Invalidate All (VTBIA) Register**



The Vector State Address Register (VSAR), shown in Figure 10–9, is a read/write register that contains a quadword-aligned virtual address of memory assigned by software for storing implementation-specific vector hardware state when the asynchronous method of handling memory management exceptions is implemented. The length of this memory area is implementation specific. Software must guarantee that accessing the memory pointed to by the address does not result in a memory management exception. If the synchronous method of handling memory management exceptions is implemented, this register is omitted. For more information, refer to Section 10.6.1, Vector Memory Management Exception Handling.

**Figure 10–9 Vector State Address Register (VSAR)**



With the exception of VPSR (and VAER), an MTPR to any other writable vector internal processor register (IPR) ensures that the new state of the IPR affects the execution of all subsequently issued vector instructions. Vector instructions issued before an MTPR to any writable vector IPR are unaffected by the new state of the IPR (and any implicitly changed vector IPR) except in one case: when the MTPR sets VPSR<RST> while VPSR<BSY> is set. (See Table 10–1 for more details.)

Except for the following two cases, the operations of the scalar and vector processors are UNDEFINED after execution of MTPR to a read-only vector IPR, MTPR to a nonexistent vector IPR, MTPR of a nonzero value to a MBZ field, or MTPR of a reserved value to a vector IPR. The preferred implementation is to cause reserved-operand fault.

- If an implementation supports an optional vector processor, but the vector processor is not installed, MTPR to VPSR has no effect.
- If an implementation supports an optional vector processor, but either the vector processor is not installed, or the scalar/vector processor pair uses a common translation buffer (TB), MTPR to VTBIA has no effect.

In each of these cases, MTPR is implemented as a no-op.

Except for the following two cases, the operations of the scalar and vector processors are UNDEFINED after execution of MFPR from a nonexistent vector IPR, or MFPR from a write-only vector IPR. The preferred implementation is to cause reserved-operand fault.

- If an implementation supports an optional vector processor, but the vector processor is not installed, MFPR from VPSR returns zero.

## VAX Vector Architecture

### 10.2 VAX Vector Architecture Registers

- If an implementation supports an optional vector processor, but the vector processor is not installed, MFPR from VMAC has no effect.

The internal processor register (IPR) assignments for these registers are found in Table 10–5.

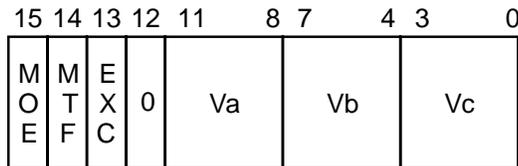
**Table 10–5 IPR Assignments**

| Offset (Hex) | IPR                                    |
|--------------|--|
| 90           | VPSR                                   |
| 91           | VAER                                   |
| 92           | VMAC                                   |
| 93           | VTBIA                                  |
| 94           | VSAR                                   |
| 95–9B        | Reserved for vector architecture use   |
| 9C–9F        | Reserved for vector implementation use |

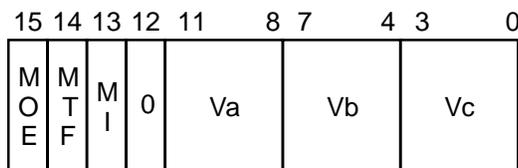
### 10.3 Vector Instruction Formats

Vector instructions use 2-byte opcodes and normal VAX operand specifiers. For more information on VAX operand specifiers, refer to the *VAX Architecture Reference Manual*. The vector registers to be used by a vector instruction are specified by the vector control word operand. The MFVP, MTVP, and Synchronize Vector Memory Access (VSYNC) instructions do not use a vector control word operand. The general format of the vector control word operand is shown in Figure 10–10. Table 10–6 describes the fields of the vector control word operand (cntrl). The actual format of the vector control word operand is instruction dependent. (Refer to the instruction descriptions later in this chapter for more detail.) The vector control word operand is passed by the VAX scalar processor to the vector processor.

**Figure 10–10 Vector Control Word Operand (cntrl)**



or



ZK–1453A–GE

**Table 10–6 Description of the Vector Control Word Operand**

| Extent | Description   |
|--------|---|
| <3:0>  | Vc. This field selects the vector register to be used as the Vc operand. For the Vector Floating Compare (VCMP) instruction, it specifies the compare function.   |
| <7:4>  | Vb. This field selects the vector register to be used as the Vb operand.  |
| <11:8> | Va. This field selects the vector register to be used as the Va operand. For the Vector Convert (VVCVT) instruction, it specifies the convert function.   |
| <12>   | 0   |
| <13>   | Modify Intent (MI). Used only in Load Memory Data into Vector Register (VLD) and VGATH instructions. instructions to indicate that a majority of the memory locations being loaded by the VLD or VGATH will later be stored into by VST/VSCAT instructions. This bit is optional to implement. See Section 10.3.3, Modify Intent bit, for more details.   |
| <13>   | Exception Enable (EXC). Used only in vector integer and floating-point instructions to enable integer overflow and floating underflow, respectively.  |
| <14>   | Match True/False (MTF). When masked operations have been enabled (cntrl<MOE> EQL 1), only elements for which the corresponding VMR bit matches cntrl<MTF> are operated on. See previous description. Cntrl<MTF> is also used by the VMERGE and IOTA instructions.   |
| <15>   | Masked Operation Enable (MOE). This bit enables operations under the control of the Vector Mask Register (VMR) for vector instructions. When set, masked operations are enabled, and only elements for which the corresponding VMR bit matches cntrl<MTF> are operated on. If cntrl<MOE> is clear, all elements are operated upon. In either case, the Vector Length Register (VLR) limits the highest element operated upon. |

The vector control word operand may determine some or all of the following:

- Enabling of masked operations
- Enabling of floating underflow for floating-point instructions and integer overflow for integer operations
- Which vector registers to use as sources, destinations, or both
- Which type of operation to perform (for the convert and compare instructions)

### 10.3.1 Masked Operations

Masked operations are enabled by the use of cntrl<15:14> of the vector control word operand. Cntrl<15> is the Masked Operation Enable (MOE) bit, and cntrl<14> is the Match True/False (MTF) bit. When cntrl<MOE> is set, masked operations are enabled. Only elements for which the corresponding Vector Mask Register (VMR) bit matches cntrl<MTF> are operated upon. If cntrl<MOE> is clear, all elements are operated upon. In either case, the Vector Length Register (VLR) limits the highest element operated upon.

Cntrl<MOE> should be zero for VMERGE and IOTA instructions; otherwise the results are UNPREDICTABLE. Both the Vector Mask Register (VMR) and the Match True/False bit (cntrl<MTF>) are always used by these instructions. VMERGE and IOTA operate upon vector register elements up to the value specified in VLR.

## VAX Vector Architecture

### 10.3 Vector Instruction Formats

#### 10.3.2 Exception Enable Bit

The vector processor does not use the IV and FU bits in the processor status longword (PSL) to enable integer overflow and floating underflow exception conditions. These exception conditions are enabled or disabled on a per instruction basis for vector integer and floating-point instructions by bit <13> in the vector control word operand (cntrl<EXC>). When cntrl<EXC> is set, floating underflow is enabled for vector floating-point instructions, and integer overflow is enabled for vector integer instructions. When cntrl<EXC> is clear, floating underflow and integer overflow are disabled. Note that for VLD/VGATH instructions bit<13> is used and labeled differently.

#### 10.3.3 Modify Intent Bit

The Modify Intent (MI) bit is used by the software to indicate to the vector processor that a majority of the memory locations being loaded by VLD/VGATH instructions will later be stored into, and so become modified, by VST/VSCAT instructions. When informed of software's intent to modify, some vector processor implementations can optimize the vector loads and stores performed on these locations.

The MI bit resides in bit<13> of the vector control word operand (cntrl<MI>) and is used only in VLD and VGATH instructions. A vector processor implementation is not required to implement cntrl<MI>.

For vector processors that implement cntrl<MI>, software uses the bit in a VLD or VGATH instruction in the following way:

- By setting cntrl<MI> to zero, software indicates that less than a majority of the locations loaded by the VLD/VGATH instructions will later be stored into by VST/VSCAT instructions.
- By setting cntrl<MI> to 1, software indicates that a majority of the locations loaded by the VLD/VGATH instructions will later be stored into by VST/VSCAT instructions.

Vector processors that do not implement cntrl<MI> ignore the setting of this bit in the control word for VLD and VGATH.

The results of VLD/VGATH and VST/VSCAT are unaffected by the setting of cntrl<MI>. This includes memory management, where access-checking is done with read intent for VLD/VGATH even if cntrl<MI> is set. However, incorrectly setting cntrl<MI> can prevent the optimization of these instructions.

#### 10.3.4 Register Specifier Fields

The Va (cntrl<11:8>), Vb (cntrl<7:4>), and Vc (cntrl<3:0>) fields of the vector control word operand are generally used to select vector registers. Some vector instructions use these fields to encode other instruction-specific information as shown later in this section.

#### 10.3.5 Vector Control Word Formats

Depending on the instruction, the vector control word can specify up to two vector registers as sources, and one vector register as a destination. Other information may be encoded in the vector control word, as shown in Figure 10–11a to Figure 10–11n. Bits that are shown as “0” should be zero (SBZ). Execution of vector instructions with illegal, inconsistent, or unspecified control word fields produces UNPREDICTABLE results.

Figure 10–11a depicts the vector control word for VLDL and VLDQ.

## VAX Vector Architecture

### 10.3 Vector Instruction Formats

Figure 10–11b depicts the vector control word for VSTL and VSTQ.

Figure 10–11c depicts the vector control word for VGATHL and VGATHQ.

Figure 10–11d depicts the vector control word for VSCATL and VSCATQ.

Figure 10–11e depicts the vector control word for VVADDL/F/D/G, VVSUBL/F/D/G, VVMULL/F/D/G, and VVDIVF/D/G.

Figure 10–11f depicts the vector control word for VVLLLL, VVSLLL, VVBISL, VVXORL, and VVBICL. Cntrl<EXC> should always be zero for these instructions, otherwise the results are UNPREDICTABLE.

Figure 10–11g depicts the vector control word for VVCMPL/F/D/G. The Vc field (cntrl<3:0>) is used to specify the compare function.

Figure 10–11h depicts the vector control word for VVCVT. The Va field (cntrl<11:8>) is used to specify the convert function.

Figure 10–11i depicts the vector control word for VVMERGE.

Figure 10–11j depicts the vector control word for VSADDL/F/D/G, VVSUBL/F/D/G, VSMULL/F/D/G, and VSDIVF/D/G.

Figure 10–11k depicts the vector control word for VSSLLL, VSSLLL, VSBISL, VSXORL, and VSBICL. Cntrl<EXC> should be zero for these instructions; otherwise, the results are UNPREDICTABLE.

Figure 10–11l depicts the vector control word for VSCMPL/F/D/G. The Vc field (cntrl<3:0>) is used to specify the compare function.

Figure 10–11m depicts the vector control word for VSMERGE.

Figure 10–11n depicts the vector control word for IOTA.

# VAX Vector Architecture

## 10.3 Vector Instruction Formats

**Figure 10–11 Vector Control Word Format**

a. Vector Control Word Format for VLDL and VLDQ

|    |    |    |    |    |   |                             |   |   |   |
|----|----|----|----|----|---|-----------------------------|---|---|---|
| 15 | 14 | 13 | 12 | 11 | 8 | 7                           | 4 | 3 | 0 |
| M  | M  | M  | 0  | 0  | 0 | dst / src<br>vec reg<br>num |   |   |   |
| O  | T  | I  |    |    |   |                             |   |   |   |
| E  | F  |    |    |    |   |                             |   |   |   |

b. Vector Control Word Format for VSTL and VSTQ

|    |    |    |    |    |   |                             |   |   |   |
|----|----|----|----|----|---|-----------------------------|---|---|---|
| 15 | 14 | 13 | 12 | 11 | 8 | 7                           | 4 | 3 | 0 |
| M  | M  | 0  | 0  | 0  | 0 | dst / src<br>vec reg<br>num |   |   |   |
| O  | T  |    |    |    |   |                             |   |   |   |
| E  | F  |    |    |    |   |                             |   |   |   |

c. Vector Control Word Format for VGATHL and VGATHQ

|    |    |    |    |    |         |           |   |   |   |
|----|----|----|----|----|---------|-----------|---|---|---|
| 15 | 14 | 13 | 12 | 11 | 8       | 7         | 4 | 3 | 0 |
| M  | M  | M  | 0  | 0  | src     | dst / src |   |   |   |
| O  | T  | I  |    |    | vec reg | vec reg   |   |   |   |
| E  | F  |    |    |    | num     | num       |   |   |   |

d. Vector Control Word Format for VSCATL and VSCATQ

|    |    |    |    |    |         |           |   |   |   |
|----|----|----|----|----|---------|-----------|---|---|---|
| 15 | 14 | 13 | 12 | 11 | 8       | 7         | 4 | 3 | 0 |
| M  | M  | 0  | 0  | 0  | src     | dst / src |   |   |   |
| O  | T  |    |    |    | vec reg | vec reg   |   |   |   |
| E  | F  |    |    |    | num     | num       |   |   |   |

e. Vector Control Word Format for VVADDL/F/D/G, VVSUBL/F/D/G, and VVDIVF/D/G

|    |    |    |    |         |         |         |   |   |   |
|----|----|----|----|---------|---------|---------|---|---|---|
| 15 | 14 | 13 | 12 | 11      | 8       | 7       | 4 | 3 | 0 |
| M  | M  | E  | 0  | src1    | src2    | dst     |   |   |   |
| O  | T  | X  |    | vec reg | vec reg | vec reg |   |   |   |
| E  | F  | C  |    | num     | num     | num     |   |   |   |

f. Vector Control Word Format for VVSLLL, VVSRL, VVBISL, VVXORL, and VVBICL

|    |    |    |    |         |         |         |   |   |   |
|----|----|----|----|---------|---------|---------|---|---|---|
| 15 | 14 | 13 | 12 | 11      | 8       | 7       | 4 | 3 | 0 |
| M  | M  | 0  | 0  | src1    | src2    | dst     |   |   |   |
| O  | T  |    |    | vec reg | vec reg | vec reg |   |   |   |
| E  | F  |    |    | num     | num     | num     |   |   |   |

g. Vector Control Word Format for VVC MPL/F/D/G

|    |    |    |    |         |         |      |   |   |   |
|----|----|----|----|---------|---------|------|---|---|---|
| 15 | 14 | 13 | 12 | 11      | 8       | 7    | 4 | 3 | 0 |
| M  | M  | 0  | 0  | src1    | src2    | cmp  |   |   |   |
| O  | T  |    |    | vec reg | vec reg | func |   |   |   |
| E  | F  |    |    | num     | num     |      |   |   |   |

h. Vector Control Word Format for VVCVT

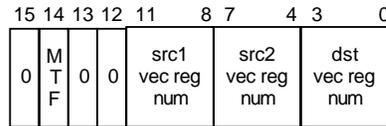
|    |    |    |    |      |         |         |   |   |   |
|----|----|----|----|------|---------|---------|---|---|---|
| 15 | 14 | 13 | 12 | 11   | 8       | 7       | 4 | 3 | 0 |
| M  | M  | E  | 0  | cvt  | src     | dst     |   |   |   |
| O  | T  | X  |    | func | vec reg | vec reg |   |   |   |
| E  | F  | C  |    |      | num     | num     |   |   |   |

ZK-5053A-GE

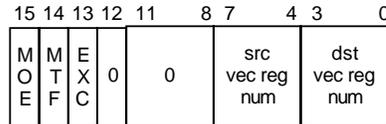
(continued on next page)

Figure 10–11 (Cont.) Vector Control Word Format

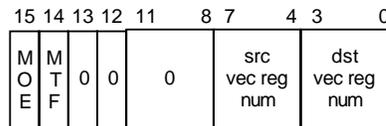
i. Vector Control Word Format for VVMERGE



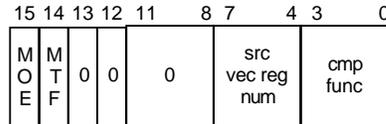
j. Vector Control Word Format for VSADDL/F/D/G, VSSUBL/F/D/G, VSMULL/F/D/G and VSDIVF/D/G



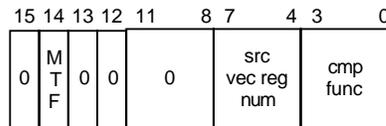
k. Vector Control Word Format for VSSLLL, VSSRLL, VSBISL, VSXORL, and VSBICL



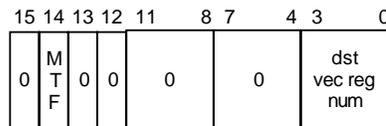
l. Vector Control Word Format for VSCMPL/F/D/G



m. Vector Control Word Format for VSMERGE



n. Vector Control Word Format for IOTA



ZK-5054A-GE

### 10.3.6 Restrictions on Operand Specifier Usage

Certain restrictions are placed on the addressing mode combinations usable within a single vector instruction. These combinations involve the logically inconsistent simultaneous use of a value as both a source operand (that is, a .rw, .rl, or .rq operand) and an address. Specifically, if within the same instruction the contents of register Rn is used as both a part of a source operand and as an address in an addressing mode that modifies Rn (that is, autodecrement, autoincrement, or autoincrement deferred), the value of the scalar source operand is UNPREDICTABLE.

Use of short literal mode for the scalar source operand of a vector floating-point instruction causes UNPREDICTABLE results.

## VAX Vector Architecture

### 10.3 Vector Instruction Formats

If a Store Vector Register Data into Memory (VST) or Scatter Memory Data into Vector Register (VSCAT) instruction overwrites anything needed for calculation of the memory addresses to be written, the result of the VST or VSCAT is UNPREDICTABLE.

If the same vector register is used as both source and destination in a Gather Memory Data into Vector Register (VGATH) instruction, the result of the VGATH is UNPREDICTABLE.

When the addressing mode of the BASE operand used in a VLD, VST, VGATH, or VSCAT instruction is immediate, the results of the instruction are UNPREDICTABLE.

#### 10.3.7 VAX Condition Codes

The vector instructions do not affect the condition codes in the processor status longword (PSL) of the associated scalar processor.

#### 10.3.8 Illegal Vector Opcodes

An illegal vector opcode is defined as a vector opcode to which no vector processor function is currently assigned. Opcodes that are not identified in Appendix D as vector opcodes are neither decoded nor executed by the vector processor.

An implementation is permitted to report an illegal vector opcode in one of the following ways:

1. Reserved-instruction fault. This is the recommended implementation.
2. Illegal vector opcode. The vector processor disables itself and sets VPSR<IVO>. The remainder of the vector processor state is left unmodified.

The way in which a particular illegal vector opcode is reported is implementation specific.

## 10.4 Assembler Notation

The assembler notation uses a format that is different from the operand specifiers for the vector instructions. The number and order of operands is not the same as the instruction-stream format. For example, vector-to-vector addition is denoted by the assembler as “VVADDL V1, V2, V3” instead of “VVADDL X123”. The assembler always generates immediate addressing mode (I#constant) for vector control word operands. The assembler notation for vector instructions uses opcode qualifiers to select whether vector processor exception conditions are enabled or disabled, and to select the value of cntrl<MTF> in masked, VMERGE, and IOTA operations. The appropriate opcode is followed by a slash (/). The following qualifiers are supported:

- The qualifier U enables floating underflow. The qualifier V enables integer overflow. Both of these qualifiers set cntrl<EXC>. The default is no vector processor exception conditions are enabled.
- The qualifier 0 denotes masked operation on elements for which the Vector Mask Register (VMR) bit is 0. The qualifier 1 denotes masked operation on elements for which the VMR bit is 1. Both qualifiers set cntrl<MOE>. The default is no masked operations.
- For the VMERGE and IOTA instructions only, the qualifier 0 denotes cntrl<MTF> is 0. The qualifier 1 denotes cntrl<MTF> is 1. Cntrl<MTF> is 1 by default. Cntrl<MOE> is not set in this case.

- For the VLD and VGATH instructions only, the qualifier M indicates modify intent (cntrl<MI> is 1). The default is no modify intent (cntrl<MI> is 0).

The following examples use several of these qualifiers:

```
VVADDF/1  V0, V1, V2  ;Operates on elements with mask bit set
VVMULD/0  V0, V1, V2  ;Operates on elements with mask bit clear
VVADDL/V  V0, V1, V2  ;Enables exception conditions
                    (integer overflow here)
VVSUBG/U0 V0, V1, V2  ;Enables floating underflow and
                    ;Operates on elements with mask bit clear

VLDL/M    base,#4,V1  ;Indicates Modify Intent
```

## 10.5 Execution Model

A typical processor consists of a VAX scalar processor and its associated vector processor, which contains vector registers and vector function units. The scalar and vector processors may execute asynchronously. The VAX scalar processor decodes both scalar and vector instructions following the operand specifier evaluation rules stated in the *VAX Architecture Reference Manual*, but executes only the scalar instructions. The scalar processor passes the information required to execute a vector instruction to the vector processor. This information may include the vector opcode, scalar source operands, and vector control words. The vector processor performs the required operation, such as loading data from memory, storing data to memory, or manipulating data already loaded into its vector registers.

The scalar processor may decode a vector instruction before checking whether the vector processor should receive it. Exceptions on vector instruction operands may occur during this decoding and may be taken before the attempt to send the decoded instruction to the vector processor. The scalar processor performs one of the following operations when sending a decoded vector instruction to the vector processor. Recall that because the vector and scalar processors can execute asynchronously, a VPSR state transition may not be seen immediately by the scalar processor.

- If the scalar processor views the vector processor as enabled (the scalar processor sees VPSR<VEN> as set), the decoded vector instruction is sent to the vector processor. The vector processor queues instructions sent by the scalar processor until they can be executed.
- If the scalar processor views the vector processor as disabled (the scalar processor sees VPSR<VEN> as clear), attempting to send the decoded vector instruction to the vector processor results in a vector processor disabled fault.

The following flow details how vector instruction decode proceeds from the scalar processor:

```
DO WHILE (the scalar processor has a decoded vector instruction for
          the vector processor)
  IF (the vector processor is viewed as disabled -- the scalar processor
      sees VPSR<VEN> as clear) THEN
```

## VAX Vector Architecture

### 10.5 Execution Model

```
        enter the vector processor disabled fault handler.
ELSE
    IF (asynchronous memory management handling is implemented
        AND VPSR<PMF> is set) THEN
        enter the memory management exception handler.
        {The vector processor clears VPSR<PMF> .}
    ELSE
        BEGIN
            {If asynchronous memory management handling is
            implemented and VPSR<MF> is set, the vector processor
            clears VPSR<MF>, and retries the faulting memory
            reference before any new vector instructions in the
            queue are executed.}
            IF (the vector processor instruction queue is not full) THEN
                BEGIN
                    Send the decoded instruction to the vector processor
                    for execution.
                    IF (the decoded instruction is a vector memory access
                        instruction AND synchronous memory management
                        handling is implemented) THEN
                        ensure instruction completion without the occurrence
                        of memory management exceptions.
                END
            END
        END
    END
```

If asynchronous memory management handling is implemented, and VPSR<MF> is set when the scalar processor sends the vector processor an instruction, the vector processor clears VPSR<MF>, and retries the faulting memory reference before any new vector instructions in the queue are executed.

The VAX scalar processor need not wait for the vector processor to complete its operation before processing other instructions. Thus, the scalar processor could be processing other VAX instructions while the vector processor is performing vector operations. However, if the scalar processor issues an MFVP instruction to the vector processor, the scalar processor must wait for the MFVP result to be written before processing other instructions.

Because the scalar and vector processors may execute asynchronously, it is possible to context switch the scalar processor before the vector processor is idle. Software is responsible for ensuring that scalar and vector memory management remains synchronized, and that all exceptions get reported in the context of the process where they occurred. This is achieved by making sure all vector memory accesses complete, and then disabling the vector processor before any scalar context switch.

The vector processor may have its own translation buffer (TB) and cache and may have separate paths to memory, or it may share these resources with the scalar processor.

#### 10.5.1 Access Mode Restrictions

In general, processes are expected to use the vector processor in only one mode. However, multimode use of the vector processor by a process is allowed. Software decides whether to allow vector processor exceptions from vector instructions executed in a previous access mode to be reported in the current mode. The preferred method is to report all vector processor exceptions in the access mode where they occurred. This is achieved by requiring a process that uses the vector

processor to execute a SYNC instruction before changing to an access mode where additional vector instructions are executed.

For correct access checking of vector memory references, the vector processor must know the access mode in effect when a vector memory access instruction is issued by the scalar processor.

### 10.5.2 Scalar Context Switching

With the addition of a vector processor, the required steps in performing a scalar context switch change. The following procedure outlines the required method software should use for scalar context switching:

1. Disable the vector processor so that no new vector instructions will be accepted. Writing zero to the VPSR using the MTPR instruction clears VPSR<VEN> and disables the vector processor without affecting VPSR<31:1>. (See Section 10.6.3, Vector Processor Disabled, for more details.)
2. Ensure that no more vector memory read or write operations can occur. Reading the VMAC internal processor register (IPR) using the MFPR instruction does the required scalar/vector memory synchronization without any exceptions being reported. Reading VMAC also ensures that all unreported hardware errors encountered by previous vector memory instructions are reported before the MFPR completes. For more information on this function of VMAC, refer to Section 10.9, Hardware Errors.
3. Set a software scalar-context-switch flag and perform a normal scalar processor context switch, for example SVPCTX, and so on, leaving the vector processor state as is.

Although not required by the architecture, software may wait for VPSR<BSY> to be clear after disabling the vector processor when performing a scalar context switch, which provides the following advantages:

- The vector processor cannot be executing non-memory-access instructions from the previous process while a normal scalar context switch to a new process is being performed—which may be desirable to an operating system.
- All unreported hardware errors encountered by previous non-memory-access instructions will be reported by the time the vector processor clears VPSR<BSY> and thus known to software before scalar-context switching continues (refer to Section 10.9, Hardware Errors, for more details).
- The MFPR from VPSR used to read VPSR<BSY> also ensures that the scalar processor views the vector processor as disabled.

If software does not wait for VPSR<BSY> to be clear, it is possible that while a normal scalar context switch to a new process is being performed, the vector processor may still be executing non-memory-access instructions from the previous process.

The required steps for Vector Context Switching are discussed in Section 10.6.4, Handling Disabled Faults and Vector Context Switching.

## VAX Vector Architecture

### 10.5 Execution Model

#### 10.5.3 Overlapped Instruction Execution

To improve performance, the vector processor may overlap the execution of multiple instructions—that is, execute them concurrently. Further, when no data dependencies are present, the vector processor may complete instructions out of order relative to the order in which they were issued. A vector processor implementation can perform overlapped instruction execution by having separate function units for such operations as addition, multiplication, and memory access. Both data-dependent and data-independent instructions can be overlapped; the former by a technique known as chaining, which is described in the next section. In many instances, overlapping allows an operation from one instruction to be performed in any order with respect to an operation of another instruction.

When vector arithmetic exceptions occur during overlapped instruction execution, exception handling software may not see the same instruction state and exception information that would be returned from strictly sequential execution. Most notably, the VAER could indicate the exception conditions and destination registers of a number of vector instructions that were executing concurrently and encountered exceptions. Exception reporting during chained execution is discussed further in Section 10.5.3.1.

To ensure correct program results and exception reporting, the architecture does place requirements on the ordering among the operations of one vector instruction and those of another. The primary goal of these requirements is to ensure that the results obtained from both the overlapped and strictly sequential execution of data-dependent instructions are identical. A secondary goal is to establish places within the instruction stream where software is guaranteed to receive the reporting of exceptions from a chain of data-dependent instructions.

In many cases, these requirements ensure the obvious: for example, an output vector register element of one arithmetic instruction must be computed before it can be used as an input element to a subsequent instruction. But, a number of the things ensured are not obvious: for example, a Memory Instruction Synchronization (MSYNC) instruction must report exceptions encountered in generating a value of Vector Mask Register (VMR) that is used in a previously issued masked store instruction.

To precisely define the requirements on the ordering among operations, Section 10.5.3.3 discusses the “dependence” among their results (the vector register elements and control register bits produced by the operations).

##### 10.5.3.1 Vector Chaining

The architecture allows vector chaining, where the results of one vector instruction are forwarded (chained) to another before the input vector of the first instruction has been completely processed. In this way, the execution of data-dependent vector instructions may be overlapped. Thus, chaining is an implementation-dependent feature that is used to improve performance.

With some restrictions stated below, the vector processor may chain a number of instructions. Usually, each instruction is performed by a separate function unit. The number and types of instructions allowed within a chained sequence (often referred to as a “chain”) are implementation dependent. Typically, implementations will attempt to chain sequences of two or three instructions such as: operate-operate, operate-store, load-operate, operate-operate-store, and load-operate-store. Load-operate-operate-store may also be possible.

The following is an example of a sequence that an implementation will often chain:

```
VVADDF V0, V1, V2  
VVMULF V2, V3, V4
```

The destination of the VVADDF is a source of the succeeding VVMULF. The VVMULF begins executing when the first sum element of the VVADDF is available.

A number of instructions within a chained sequence can encounter exceptions. For each instruction that encounters an exception, the vector processor records the exception condition type and destination register number in the Vector Arithmetic Exception Register (VAER). When the last instruction within the chain completes, the VAER will show the exception condition type and destination register number of all instructions that encountered exceptions within the chain. Furthermore, when the vector processor disabled fault is finally generated for the exceptions, the VAER may also indicate exception state for instructions issued after the last instruction within the chain. This effect is possible due to the asynchronous exception-reporting nature of the vector processor.

Furthermore, for each instruction that encounters an exception within a chain, the default result, as defined in Section 10.6.2, is forwarded as the source operand to the next instruction. This has the effect that default results and exceptions can propagate down through a chain. Note that the default result of one instruction may be overwritten by another instruction before the exception is taken.

Consider the following:

```
VVADDG V1, V2, V3 ;gets Floating Overflow  
VGEQG V3, V4 ;gets Floating Reserved Operand  
VVMULG V4, V5, V3 ;overwrites V3
```

For the previous example, assume that an exception is taken after the completion of the VVMULG. The VAER will indicate: Floating Overflow and Floating Reserved Operand exception condition types; and V3 as a destination register. However, no default result will be found in the appropriate element of V3 because it has been overwritten by the VVMULG.

The architecture allows a vector load to be chained into a vector operate instruction provided the operate instruction can be suspended and resumed to produce the correct result if the vector load gets a memory management exception. Consider this example:

```
VLDL A, #4, V0  
VVADDF V0, V1, V1
```

In synchronous memory management mode, the VVADDF cannot be chained into the VLDL until the VLDL is ensured to complete without a memory management exception. This occurs because the scalar processor is not even allowed to issue the VVADDF to the vector processor until the memory management checks for the VLDL have been completed. In asynchronous memory management mode, the VVADDF may be chained into the VLDL prior to the completion of memory management exception checking. This is possible because a memory management exception in asynchronous memory management mode provides sufficient state to restart both the VLDL and the VVADDF when the memory management exception is corrected.

## VAX Vector Architecture

### 10.5 Execution Model

The architecture allows a vector operate instruction to be chained into a store instruction. If the vector operate instruction encounters an arithmetic exception, the exception condition type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER). The default result generated by that instruction (in some cases an encoded reserved operand) may be written to memory by the store instruction before the exception is reported.

#### 10.5.3.2 Register Conflict

When overlapping the execution of instructions, the vector processor must deal with register conflict. This occurs when one instruction is intending to write a register while previously issued instructions are reading from that register. The following is an example of vector register conflict:

```
VVADDF V1, V2, V3
VVMULF V4, V5, V1
```

In the example, the VVADDF and VVMULF cannot both begin execution simultaneously because the elements of V1 generated by the VVMULF would overwrite the original elements of V1 required as input by the VVADDF. However, a vector processor implementation can still overlap the execution of these two instructions in a number of ways. One way would be by not starting the VVMULF until the first element of V1 has been read by the VVADDF. In this manner, as the VVADDF reads the next elements from V1 and V2, the VVMULF writes its product into the previous element of V1. This process continues until all the elements have been processed by both instructions. The VVADDF will finish execution while the VVMULF still has at least one product to store.

In the case of the Vector Mask Register (VMR), the vector processor ensures that register conflict does not occur. This is often accomplished by making a copy of the VMR value under which a pending vector instruction is to execute, and using this copy when execution begins. This allows the vector processor to begin executing an instruction that writes VMR before it completes prior instructions that read VMR.

#### 10.5.3.3 Dependencies Among Vector Results

To achieve correct results and exception reporting during overlapped execution, the vector processor must maintain certain dependencies among the register elements and control register bits produced by various vector instructions. Because of the vector processor's asynchronous exception reporting nature and out-of-order completion of instructions, these dependencies differ from those ensured by the VAX scalar processor. In addition, these dependencies are at the level of vector register elements and vector control register bits; rather than at the level of vector registers and vector control registers.

Among other things, these dependencies determine the exception reporting nature of the MFVP instruction. The value of the vector control register (VCR, VLR, VMR<31:0>, VMR<63:32>) delivered by an MFVP depends upon the value of certain vector register elements and vector control register bits. Unreported exceptions that occur in the production of these elements and control register bits are reported by the vector processor prior to the completion of the MFVP from the vector control register.

The dependencies are expressed formally for the various classes of vector instructions by the tables of pseudo-code in this section. These are the only dependencies that software should rely upon the vector processor to ensure.

A vector processor implementation is allowed to ensure more than just these dependencies providing that this larger set of dependencies yields correct results and exception reporting.

---

**Note**

---

Note the implications of the following sequence for Table 10–7, Table 10–8, Table 10–9, Table 10–10, Table 10–11, Table 10–12, Table 10–13, and Table 10–14:

```
VVSUBF V5, V6, V7
VVADDF V1, V2, V3
VVMULF V7, V7, V3
VVDIVF V1, V4, V7
```

Implicit in statements of the form: “result DEPENDS on B” is the requirement that the result depends only on the value of “B” generated by the most immediate previously issued instruction relative to the result’s own generating instruction. For instance, in the following example, the V3 produced by the VVMULF has the dependence: “V3[i] DEPENDS on V7[i]”. This means that the value of V3[i] produced by the VVMULF depends only on the value of V7[i] produced by the VVADDF.

---

**Table 10–7 Dependencies for Vector Operate Instructions**

| Instructions   | Dependence  |
|--|---|
| VVADDx, VSADDx,<br>VVSUBx, VSSUBx,<br>VVMULx, VSMULx,<br>VVDIVx, VSDIVx,<br>VVCVTxy, VVBICL,<br>VSBICL, VVBISL,<br>VSBISL, VVXORL,<br>VSXORL, VVSLLL,<br>VSSLLL, VVSRLl,<br>VSSRLL | <pre>for i = 0 to VLR-1   begin     Vc[i] DEPENDS on VLR;     if {MOE EQL 1} then Vc[i] DEPENDS on VMR&lt;i&gt;;     if ( {MOE EQL 1} AND {VMR&lt;i&gt; EQL MTF} ) OR {MOE EQL 0} then       begin         Vc[i] DEPENDS on Vb[i];         if {Vector-Vector Operation} AND NOT {VVCVTxy} then           Vc[i] DEPENDS on Va[i];         end;       end;   end;</pre> |

## VAX Vector Architecture

### 10.5 Execution Model

**Table 10–8 Dependencies for Vector Load and Gather Instructions**

| Instructions | Dependence  |
|--------------|---|
| VLDx, VGATHx | <pre> for i = 0 to VLR-1   begin     Vc[i] DEPENDS on VLR;     if {MOE EQL 1} then Vc[i] DEPENDS on VMR&lt;i&gt;;     if ( {MOE EQL 1} AND {VMR&lt;i&gt; EQL MTF} ) OR {MOE EQL 0} then       if VGATH then         begin           Vc[i] DEPENDS on Vb[i];           k = BASE + Vb[i];         end       else         k = BASE + i * STRIDE;     Vc[i] DEPENDS on LOAD_COMPLETED(k);   end; </pre> |

**Table 10–9 Dependencies for Vector Store and Scatter Instructions**

| Instructions | Dependence   |
|--------------|--|
| VSTx, VSCATx | <pre> j = 0; for i = 0 to VLR-1   begin     if ( {MOE EQL 1} AND {VMR&lt;i&gt; EQL MTF} ) OR {MOE EQL 0} then       begin         if {MOE EQL 1} then ELEMENT_STORED[j] depends on VMR&lt;i&gt;;         ELEMENT_STORED[j] DEPENDS on Vc[i];         ELEMENT_STORED[j] DEPENDS on VLR;         if VSCAT then           begin             ELEMENT_STORED[j] DEPENDS on Vb[i];             k = BASE + Vb[i];           end         else           k = BASE + i * STRIDE;         STORE_COMPLETED(k) DEPENDS on ELEMENT_STORED[j];         j = j+1;       end;     end;   end; </pre> |

**Table 10–10 Dependencies for Vector Compare Instructions**

| Instructions   | Dependence  |
|----------------|---|
| VVCMPx, VSCMPx | <pre> for i = 0 to VLR-1   begin     VMR&lt;i&gt; DEPENDS on VLR;     if {MOE EQL 1} then VMR&lt;i&gt; DEPENDS on VMR&lt;i&gt;     if ( {MOE EQL 1} AND {VMR&lt;i&gt; EQL MTF} ) OR {MOE EQL 0} then       begin         VMR&lt;i&gt; DEPENDS on Vb[i];         if VVCMP then VMR&lt;i&gt; DEPENDS on Va[i];       end;     end; </pre> |

**Table 10–11 Dependencies for Vector MERGE Instructions**

| Instructions        | Dependence  |
|---------------------|---|
| VVMERGE,<br>VSMERGE | <pre> for i = 0 to VLR-1   begin     Vc[i] DEPENDS on VLR;     Vc[i] DEPENDS on VMR&lt;i&gt;;     if {VMR&lt;i&gt; EQL MTF} then       begin         if VVMERGE then Vc[i] DEPENDS on Va[i];       end     else       Vc[i] DEPENDS on Vb[i];     end; </pre> |

**Table 10–12 Dependencies for IOTA Instruction**

| Instruction | Dependence   |
|-------------|--|
| IOTA        | <pre> j = 0; for i = 0 to VLR-1   begin     Vc[j] DEPENDS on VLR;     if {VMR&lt;i&gt; EQL MTF} then       begin         Vc[j] DEPENDS on VMR&lt;0..i&gt;;         j = j+1;       end;     end;   VCR DEPENDS on VMR&lt;0..VLR-1&gt;; </pre> |

## VAX Vector Architecture

### 10.5 Execution Model

**Table 10–13 Dependencies for MFVP Instructions**

| Instructions | Dependence  |
|--------------|---|
| MSYNC        | DEPENDS on the following: <ul style="list-style-type: none"> <li>• All STORE_COMPLETED(x) of previously issued VST and VSCAT instructions</li> <li>• All LOAD_COMPLETED(X) of previously issued VLD and VGATH instructions</li> </ul> |
| SYNC         | DEPENDS on the vector register elements and vector control register bits produced and stored by all previous vector instructions  |
| MFVMRLO      | DEPENDS on VMR<0..31>   |
| MFVMRHI      | DEPENDS on VMR<32..63>  |
| MFVCR        | DEPENDS on VCR  |
| MFVLR        | DEPENDS on VLR  |

**Table 10–14 Miscellaneous Dependencies**

| Item                       | Dependence   |
|----------------------------|--|
| VSYNC                      | Depends on nothing, but for each memory location, x forces all subsequent LOAD_COMPLETED(x) and STORE_COMPLETED(x) to DEPEND on all previous LOAD_COMPLETED(x) and STORE_COMPLETED(x). |
| MTVP                       | DEPENDS on nothing.  |
| Value of a memory location | The value of a memory location DEPENDS on nothing and is not DEPENDED on by any vector instruction.  |
| Transitive dependence      | $\text{if } \{a \text{ DEPENDS on } b\} \text{ AND } \{b \text{ DEPENDS on } c\} \text{ then } a \text{ DEPENDS on } c$  |

## 10.6 Vector Processor Exceptions

There are two major classes of vector processor exceptions as follows:

- Vector memory management
  - Access control violation
    - Vector access control violation
    - Vector alignment
    - Vector I/O space reference
  - Translation not valid
  - Modify
- Vector Arithmetic
  - Floating underflow
  - Floating divide by zero
  - Floating reserved operand
  - Floating overflow
  - Integer overflow



## VAX Vector Architecture

### 10.6 Vector Processor Exceptions

The architecture allows an implementation to choose one of two methods for dealing with vector processor memory management exceptions. The two methods are as follows:

- Synchronous memory management handling and restart from the beginning.
- Asynchronous memory management handling and store/reload implementation-specific state using VSAR.

With the synchronous method, no new instructions are processed by the vector or the scalar processor until the vector memory access instruction is guaranteed to complete without incurring memory management exceptions. In such an implementation, the vector memory access instruction is backed up when a memory management exception occurs and a normal VAX memory management (access control violation, translation not valid, modify) fault taken with the program counter (PC) pointing to the faulting vector memory access instruction. If the synchronous method is implemented, VSAR is omitted. After fixing the vector processor memory management exception, software may REI back to the faulting vector instruction. Alternately, software may context switch to another process. For further details, see Section 10.6.4.

With the asynchronous method, vector memory management exceptions set VPSR<PMF> and VPSR<MF>. The vector processor does not inform the scalar processor of the exception condition; the scalar processor continues processing instructions. All pending vector instructions that have started execution are allowed to complete if their source data is valid. The scalar processor is notified of an exception condition or conditions when it sends the next vector instruction to the vector processor and a normal VAX memory management fault is taken. The saved PC points to this instruction, which is not the vector memory access instruction that incurred the memory management exception. At this point, the vector processor clears VPSR<PMF>. After fixing the vector processor memory management exception, software may allow the current scalar/vector process to continue. Before vector processor instruction execution resumes using state that already exists in the vector processor, the vector processor clears VPSR<MF> and the faulting memory reference is retried. Alternately, software may context switch to another process. For further details, see Section 10.6.4.

When a vector processor memory management exception is encountered by a VLD or VGATH instruction, the contents of the destination vector register elements are UNPREDICTABLE. When a vector processor memory management exception is encountered by a VSTL or VSCAT instruction, it is UNPREDICTABLE whether the vector processor writes any result location for which an exception did not occur. In either case, if the fault condition can be eliminated by software and the instruction restarted, then the vector processor will ensure that all destination register elements or result locations are written.

#### 10.6.2 Vector Arithmetic Exceptions

Vector operate instructions are always executed to completion, even if a vector arithmetic exception occurs. If an exception occurs, a default result is written. The default result is as follows:

- The low-order 32 bits of the true result for integer overflow.
- Zero for floating underflow if exceptions are disabled.

- An encoded reserved operand for floating divide by zero, floating overflow, reserved operand, and enabled floating underflow. For vector convert instructions that convert floating-point data to integer data, where the source element is a reserved operand, the value written to the destination element is UNPREDICTABLE.

The exception condition type and destination register number are always recorded in the Vector Arithmetic Exception Register (VAER) when a vector arithmetic exception occurs. Refer to Section 10.2.3, Internal Processor Registers, for more information.

### 10.6.3 Vector Processor Disabled

As a result of error conditions or software control, the vector processor signals the scalar processor not to issue any more vector instructions. The vector processor is disabled when this signal is generated and its state is reflected in VPSR<VEN>. Because the scalar and vector processors can execute asynchronously, the scalar processor may not receive this signal immediately. As a result, the scalar processor may continue to view the vector processor as enabled and send it vector instructions. Once the scalar processor receives this signal, it will view the vector processor as disabled and will not send it any more vector instructions (including MFVP/MTVP). While the vector processor is disabled, and in the absence of hardware errors, it will complete all pending instructions in its instruction queue including those sent by the scalar processor after the vector processor became disabled.

The vector processor can either disable itself or be disabled by software. The following error conditions cause the vector processor to disable itself:

- Vector arithmetic exception (flagged by VPSR<AEX>)
- Hardware error (flagged by VPSR<IMP> in some implementations)
- On some implementations, receipt of an illegal vector opcode (flagged by VPSR<IVO>)

In these cases, the vector processor clears VPSR<VEN> and flags the error condition by setting the appropriate bit in VPSR. (See Table 10–1.)

Software disables the vector processor by writing a zero into VPSR<VEN> using an MTPR instruction. Once the vector processor is disabled, only software can enable it. The software does this by writing a one to VPSR<VEN> using an MTPR. Recall that after performing an MTPR to VPSR, software must then issue an MFPR from VPSR to ensure that the new state of VPSR will affect the execution of subsequently issued vector instructions. The MFPR will not complete in this case until the new state of the vector processor becomes visible to the scalar processor.

When the vector processor disables itself due to a hardware error, it is implementation dependent whether the vector processor completes any pending vector instruction. However, in this case, the vector processor ensures when it is reenabled that all incompleting instructions have been flushed from the instruction queue.

If the scalar processor attempts to issue a vector instruction after it views the vector processor as disabled, then a vector processor disabled fault occurs. The vector processor disabled fault uses SCB offset 68 (hex). The exception handling software (running on the scalar processor) can then read the vector internal processor registers (IPRs) with MFPR instructions to determine what exception

## VAX Vector Architecture

### 10.6 Vector Processor Exceptions

conditions are recorded in the vector processor and if the vector processor is still busy processing other unfinished instructions.

Once the scalar processor views the vector processor as disabled, the only operations that can be issued to the vector processor are MTPR and MFPR to and from the vector IPRs.

#### 10.6.4 Handling Disabled Faults and Vector Context Switching

The following flow outlines the required steps for handling a vector processor disabled fault.

If the new process executing on the scalar processor has a vector instruction to execute, saving and restoring the state of the vector processor—that is, vector context switching—is done as part of handling a subsequent vector processor disabled fault.

If a vector processor disabled fault occurs and the current scalar process is also the current vector process, then software must perform the following procedure:

1. Obtain the vector processor status by reading the VPSR using the MFPR instruction.
2. Perform the following checks to see if any of these conditions caused the vector processor to be disabled. If any of these conditions exist, a decision to not continue this flow may occur.
  - a. If VPSR<IVO> is set, then write one to clear VPSR<IVO> using the MTPR instruction, and report an illegal vector opcode error.
  - b. If VPSR<IMP> is set, then write one to clear VPSR<IMP> using the MTPR instruction, and report an implementation-specific error.
  - c. If VPSR<AEX> is set, then write one to clear VPSR<AEX> using the MTPR instruction, and enter the vector arithmetic exception handler with information in VAER.
3. If the software scalar-context-switch flag is set, indicating that a scalar context switch has been done, then perform the following:
  - a. Make sure the vector processor has access to correct POLR, POBR, P1LR, and P1BR values.
  - b. If any vector translation buffer needs to be invalidated, then write zero into the VTBIA IPR using the MTPR instruction. Vector translation buffer flushing is required if the process was swapped out and the mapping change has not yet been made known to the vector translation buffer.
  - c. Clear the software scalar-context-switch flag.
4. Enable the vector processor by writing one to VPSR<VEN> using the MTPR instruction. Ensure the new state of the vector processor becomes visible to the scalar processor by reading VPSR with the MFPR instruction.
5. REI to retry the vector instruction at the time of the vector processor disabled fault. If there is an asynchronous memory management exception pending, it is taken when that vector instruction is reissued to the vector processor.

## VAX Vector Architecture

### 10.6 Vector Processor Exceptions

If a vector processor disabled fault occurs and the current scalar process is not the current vector process, then software must perform the following procedure:

1. Check if there is a current vector process. If there is one, then perform the following procedure:
  - a. Wait for VPSR<BSY> to be clear using the MFPR instruction.
  - b. Perform the following check to see if this condition caused the vector processor to be disabled. If this condition exists, a decision to not continue this flow may occur.
    1. If VPSR<IMP> is set, then report an implementation-specific error.
    2. If VPSR<IVO> is set, then set a software IVO flag for this process. The illegal vector opcode error is handled when this process next tries to execute in the vector processor.
    3. If VPSR<AEX> is set, then set a software AEX flag for this process, and save vector arithmetic exception state from VAER using the MFPR instruction. Any vector arithmetic exception conditions are handled when this process next tries to execute in the vector processor.
  - c. At this point there cannot be a synchronous memory management exception pending. But, if asynchronous memory management handling is implemented, there may be an asynchronous memory management exception pending. Because scalar/vector memory synchronization was required before scalar context switching, all such pending exceptions are known at this time. So, if VPSR<PMF> is set, then perform the following procedure:
    1. Set a software asynch-memory-exception-pending flag for this process.
    2. Store implementation-specific vector state in memory starting at the address in VSAR by writing one to VPSR<STS> using the MTPR instruction.
  - d. Reset the vector processor state to clear VAER and VPSR, and enable the vector processor. Writing a one to both VPSR<RST> and VPSR<VEN> using the same MTPR instruction accomplishes this. Ensure the new state of the vector processor becomes visible to the scalar processor by reading VPSR with the MFPR instruction.
  - e. Store the current vector (V0–V15) and vector control (VLR, VMR, and VCR) register values using VST and MFVP instructions.
  - f. Read the VMAC IPR using the MFPR instruction. This ensures scalar/vector memory synchronization and that all hardware errors encountered by previous vector memory instructions have been reported.
2. Make the current scalar process also the current vector process.
3. Clear the software scalar-context-switch flag.
4. Make sure the vector processor has access to correct P0LR, P0BR, P1LR, and P1BR values, and invalidate any vector translation buffer by writing zero to the VTBI IPR using the MTPR instruction.
5. Load the saved vector (V0–V15) and vector control (VLR, VMR, and VCR) register values using VLD and MTVP instructions.

## VAX Vector Architecture

### 10.6 Vector Processor Exceptions

6. If the software IMP, IVO, or AEX flags for this process are set, perform the following procedure:
  - a. Disable the vector processor by writing zero to VPSR<VEN> using the MTPR instruction. Ensure the new state of the vector processor becomes visible to the scalar processor by reading VPSR with the MFPR instruction.
  - b. If set, clear the software IMP flag for this process and finish handling the implementation-specific error. A decision to not continue this flow may occur.
  - c. If set, clear the software IVO flag for this process and report an illegal vector opcode error occurred. A decision to not continue this flow may occur.
  - d. If set, clear the software AEX flag for this process and enter the vector arithmetic exception handler with saved VAER state. A decision to not continue this flow may occur.
7. If the software async-memory-exception-pending flag for this process is set, perform the following procedure:
  - a. Clear the software async-memory-exception-pending flag for this process.
  - b. Send the vector processor the memory address that points to implementation-specific vector state for this process by writing VSAR using the MTPR instruction.
  - c. Reload the implementation-specific vector state for this process and leave the vector processor enabled by writing one to both VPSR<RLD> and VPSR<VEN> using the same MTPR instruction. From this state, the vector processor determines if VPSR<PMF>, VPSR<MF>, or both need to be set, and does it. Ensure the new state of the vector processor becomes visible to the scalar processor by reading VPSR with the MFPR instruction.
8. REI to retry the vector instruction at the time of the vector processor disabled fault. If there is an asynchronous memory management exception pending, it is taken when that vector instruction is reissued to the vector processor.

#### 10.6.5 MFVP Exception Reporting Examples

This section gives examples of Move from Vector Processor (MFVP) exception reporting that are ensured by the vector processor. The rules used to determine the correct result for each example are found in: the tables of dependencies found in Section 10.5.3.3, the description of MSYNC in Section 10.7.2, and the description of MFVP in Section 10.15.

##### Examples of Exceptions That Cause MSYNC to Fault

The following examples illustrate which exceptions are ensured by the vector processor to always cause MSYNC to fault:

## VAX Vector Architecture 10.6 Vector Processor Exceptions

1. VVMULF    V1, V1, V2  
    VVADDF    V3, V2, V3  
    MTVLR     #1  
    VSTL     V2, A, #4  
    VVCVTFD    V2, V3  
    MSYNC     R0

The MSYNC faults if exceptions occur in the production of V2[0] by the VVMULF or in the storage of V2[0] by the VSTL. MSYNC need not fault if exceptions occur in the production of: V2[1..VLR-1] by the VVMULF, V3[0..VLR-1] by the VVADDF, or V3[0..VLR-1] by the VVCVTFD.

2. VVADDF    V1, V1, V0  
    VLDL     A, #4, V0  
    MSYNC     R0

The MSYNC faults if exceptions occur in the loading of V0[0..VLR-1] from memory. MSYNC need not fault if exceptions occur in the production of V0[0..VLR-1] by the VVADDF.

3. VVADDF    V1, V1, V2  
    VLDL     A, #4, V1  
    MSYNC     R0

The MSYNC faults if exceptions occur in the loading of V1[0..VLR-1] from memory. MSYNC need not fault if exceptions occur in the production of V2[0..VLR-1] by the VVADDF.

4. VVMULF    V1, V1, V2  
    VVGTRF    V2, V3  
    VSTL/1    V0, A, #4  
    MSYNC     R0

The MSYNC faults if exceptions occur: in the production of V2[0..VLR-1] by the VVMULF, in the production of VMR<0..VLR-1> by the VVGTRF, or in the storage by the VSTL/1 of elements of V0 for which the corresponding VMR bit is one.

### Examples of Exceptions the Processor Reports Prior to MFVP Completion

The following examples illustrate which exceptions the vector processor will report prior to the completion of an MFVP from a vector control register:

1. VLDL        A, #4, V1  
    VVMULF    V1, V1, V2  
    MTVLR     #1  
    VVGTRF    V2, V3  
    MFVMRHI            R1  
    MFVMRLO            R2

Unreported exceptions that occur: in the loading of V1[0] from memory by the VLDL, in the production of V2[0] by the VVMULF, and VMR<0> by the VVGTRF are reported by the vector processor prior to the completion of the MFVMRLO. The vector processor need not at that time report any exceptions that occur in the loading of V1[1..63] from memory by the VLDL or in the production of V2[1..63] by the VVMULF. Note that the vector processor need not report any exceptions before completing MFVMRHI.

## VAX Vector Architecture

### 10.6 Vector Processor Exceptions

2. VVGTRF V0, V1  
MTVMRLO #patt  
MFVMRLO R1

For any value of “i” in the range of 0 to 31 inclusive: the value of VMR<i> delivered by MFVMRLO only depends on the value placed into VMR<i> by the MTVMRLO. As a result, the vector processor need not report exceptions that occur in the production of VMR by the VVGTRF prior to completing the MFVMRLO.

3. VVMULF/1 V1, V1, V2  
MTVMRLO #patt  
MFVMRLO R1

For any value of “i” in the range of 0 to 31 inclusive: the value of VMR<i> delivered by MFVMRLO only depends on the value placed into VMR<i> by the MTVMRLO. As a result, the vector processor need not report exceptions that occur in the production of V2[0..VLR-1] by the VVMULF/1 prior to completing the MFVMRLO.

4. MTVLR #64  
VVMULF V0, V0, V2  
VVGTRF V0, V2  
MTVLR #32  
IOTA #str, V4  
MFVCR R1

Prior to the completion of the MFVCR, the vector processor must report any exceptions that occurred in the production of V2[0..31] by the VVMULF and VMR<0..31> by the VVGTRF. Note that VCR produced by an IOTA depends only on VMR<0..VLR-1>. Recall that no exceptions can occur in the production of V4[0..VCR-1] by IOTA.

5. MTVLR #64  
VLDL A, #4, V2  
VVGTRF V0, V1  
VSGTRF/1 #3.0, V2  
MFVMRLO R1

For any value of “i” in the range of 0 to 31 inclusive: prior to the completion of the MFVMRLO, the vector processor must report any exceptions that occurred: in the loading of V2[i] from memory for which V0[i] is greater than V1[i], in the production of VMR<0..31> by the VVGTRF, and in the production of VMR<0..31> by the VSGTRF/1.

6. VVMULF V1, V1, V1  
VSTL V1, base, #str  
MTVMRLO base  
MFVMRLO R1

In this example, the value of VMR<31:0> delivered by MFVMRLO only depends on the value placed into VMR<31:0> by the MTVMRLO – whether this value is V1[0] or the previous value of the location is UNPREDICTABLE. As a result, the vector processor need not report exceptions that occur in the production of V1 by the VVMULF or in the storage of V1 by the VSTL.

## 10.7 Synchronization

For most cases, it is desirable for the vector processor to operate concurrently with the scalar processor so as to achieve good performance. However, there are cases where the operation of the vector and scalar processors must be synchronized to ensure correct program results. Rather than forcing the vector processor to detect and automatically provide synchronization in these cases, the architecture provides software with special instructions to accomplish the synchronization. These instructions synchronize the following:

- Exception reporting between the vector and scalar processors
- Memory accesses between the scalar and vector processors
- Memory accesses between multiple load/store units of the vector processor

Software must determine when to use these synchronization instructions to ensure correct results.

The following sections describe the synchronization instructions.

### 10.7.1 Scalar/Vector Instruction Synchronization (SYNC)

A mechanism for scalar/vector instruction synchronization between the scalar and vector processors is provided by SYNC, which is implemented by the MFVP instruction. SYNC allows software to ensure that the exceptions of previously issued vector instructions are reported before the scalar processor proceeds with the next instruction. SYNC detects both arithmetic exceptions and asynchronous memory management exceptions and reports these exceptions by taking the appropriate VAX instruction fault. Once it issues the SYNC, the scalar processor executes no further instructions until the SYNC completes or faults.

In beginning the execution of SYNC, the vector processor determines if any previously issued vector instruction has encountered exceptions which have yet to be reported to the scalar processor. If so, the SYNC is faulted; otherwise, the vector processor waits for either of the following conditions to be true:

- A pending or currently executing vector instruction encounters an exception—in which case the SYNC faults
- The vector processor determines that all pending and currently executing vector instructions (including memory instructions in asynchronous memory management mode) will execute to completion without encountering vector exceptions. In that case the SYNC completes.

When SYNC completes, a longword value (which is UNPREDICTABLE) is returned to the scalar processor. The scalar processor writes the longword value to the scalar destination of the MFVP and then proceeds to execute the next instruction. If the scalar destination is in memory, it is UNPREDICTABLE whether the new value of the destination becomes visible to the vector processor until scalar/vector memory synchronization is performed.

When SYNC faults, it is not completed by the vector processor and the scalar processor does not write a longword value to the scalar destination of the MFVP. Also, depending on the exception condition encountered, the SYNC itself takes either a vector processor disabled fault or memory management fault. If both faults are encountered while the vector processor is performing SYNC, then the SYNC itself takes a vector processor disabled fault. Note that it is UNPREDICTABLE whether the vector processor is idle when the fault is

## VAX Vector Architecture

### 10.7 Synchronization

generated. After the appropriate fault has been serviced, the SYNC may be returned to through an REI.

SYNC only affects the scalar/vector processor pair that executed it. It has no effect on other processors in a multiprocessor system.

#### 10.7.2 Scalar/Vector Memory Synchronization

Scalar/vector memory synchronization allows software to ensure that the memory activity of the scalar/vector processor pair has ceased and the resultant memory write operations have been made visible to each processor in the pair before the pair's scalar processor proceeds with the next instruction. Two ways are provided to ensure scalar/vector memory synchronization: using MSYNC, which is implemented by the MFVP instruction, and using the MFPR instruction to read the VMAC (Vector Memory Activity Check) internal processor register (IPR). Section 10.7.2.1 discusses MSYNC in detail. Section 10.7.2.2 discusses VMAC in detail.

Scalar/vector memory synchronization does not mean that previously issued vector memory instructions have completed; it only means that the vector and scalar processors are no longer performing memory operations. While both VMAC and MSYNC provide scalar/vector memory synchronization, MSYNC performs significantly more than just that function. In addition, VMAC and MSYNC differ in their exception behavior.

Note that scalar/vector memory synchronization only affects the scalar/vector processor pair that executed it. It has no effect on other processors in a multiprocessor system. Scalar/vector memory synchronization does not ensure that the write operations made by one scalar/vector pair are visible to any other scalar or vector processor. Software can make data visible and shared between a scalar/vector pair and other scalar and vector processors by using the mechanisms described in the *VAX Architecture Reference Manual*. Software must first make a memory write operation by the vector processor visible to its associated scalar processor through scalar/vector memory synchronization before making the write operation visible to other processors. Without performing this scalar/vector memory synchronization, it is UNPREDICTABLE whether the vector memory write will be made visible to other processors even by the mechanisms described in the *VAX Architecture Reference Manual*.

Lastly, waiting for VPSR<BSY> to be clear does not guarantee that a vector write operation is visible to the scalar processor.

##### 10.7.2.1 Memory Instruction Synchronization (MSYNC)

While MSYNC performs scalar/vector memory synchronization, it does more than that. MSYNC allows software to ensure that all previously issued memory instructions of the scalar/vector processor pair are complete and their results made visible before the scalar processor proceeds with the next instruction.

MSYNC is implemented through the nonprivileged MFVP instruction. Arithmetic and asynchronous memory management exceptions encountered by previous vector instructions can cause MSYNC to fault.

Once it issues MSYNC, the scalar processor executes no further instructions until MSYNC completes or faults.

MSYNC completes when the following events occur:

- All previously issued scalar and vector memory instructions have completed.

- All resultant memory write operations (scalar write operations and vector store operations) have been made visible to both the scalar and vector processor.
- No exception that should cause MSYNC to fault has occurred. (See the next paragraph.)

MSYNC faults when any unreported exception has occurred in the production or storage of any result (vector register element or vector control register bit) that MSYNC depends upon. Such results include all elements loaded or stored by a previously issued vector memory instruction as well as any element or control register bit that these elements depend upon.

It is UNPREDICTABLE whether MSYNC faults due to exceptions that occur in the production and storage of results (vector register elements and vector control register bits) that MSYNC does not depend upon. Software should not rely on such exceptions being reported by MSYNC for program correctness.

When MSYNC completes, a longword value (which is UNPREDICTABLE) is returned to the scalar processor, which writes it to the scalar destination of the MFVP. The scalar processor then proceeds to execute the next instruction. If the scalar destination is in memory, it is UNPREDICTABLE whether the new value of the destination becomes visible to the vector processor until another scalar/vector memory synchronization instruction is performed.

When MSYNC faults, it is not ensured that all previously issued scalar and vector memory instructions have finished. In this case, the scalar processor writes no longword value to the scalar destination of the MFVP. Depending on the exception encountered by the vector processor, the MSYNC takes a vector processor disabled fault or memory management fault. Note that it is UNPREDICTABLE whether the vector processor is idle when the fault is generated. After the fault has been serviced, the MSYNC may be returned to through an REI.

Section 10.5.3.3 gives the necessary rules and examples to determine what vector control register elements and vector control register bits MSYNC depends upon.

#### 10.7.2.2 Memory Activity Completion Synchronization (VMAC)

Privileged software needs a way to ensure scalar/vector memory synchronization that will not result in any exceptions being reported. Reading the VMAC internal processor register (IPR) with the privileged MFPR instruction is provided for these situations. It is especially useful for context switching.

Once a MFPR from VMAC is issued by the scalar processor, the scalar processor executes no further instructions until VMAC completes, which it does when the following events occur:

- All vector and scalar memory activities have ceased.
- All resultant memory write operations have been made visible to both the scalar and vector processor.
- A longword value (which is UNPREDICTABLE) is returned to the scalar processor.

After writing the longword value to the scalar destination of the MFPR, the scalar processor then proceeds to execute the next instruction. If the scalar destination is in memory, it is UNPREDICTABLE whether the new value of the destination becomes visible to the vector processor until another scalar/vector memory synchronization operation is performed.

## VAX Vector Architecture

### 10.7 Synchronization

As stated in Section 10.7.2, Scalar/Vector Memory Synchronization, the ceasing of vector and scalar memory activities does not mean that previously issued vector memory instructions have completed. For example, consider a vector memory instruction that has suspended execution due to an asynchronous memory management exception or hardware error. Once it becomes suspended, the instruction will write no further elements and its memory activity will cease. As a result, a subsequently issued VMAC will complete as soon as those write operations that were made by the memory instruction before it was suspended are visible to both the scalar and vector processor. But, after the completion of the VMAC, the memory instruction is not completed and remains suspended.

Vector arithmetic and memory management exceptions of previous vector instructions never fault an MFPR-from-VMAC and never suspend its execution.

#### 10.7.3 Other Synchronization Between the Scalar and Vector Processors

Synchronization between the scalar and vector processors also occurs in the following situations:

- In the absence of pending vector arithmetic exceptions, reading a vector control register using the MFVP instruction waits for all previous write operations to that register to complete. In addition, the scalar processor must wait for the MFVP result to be written before processing other instructions. An MFVP instruction that reads a vector control register must fault if there is any unreported exception that has occurred in the production of the value of the control register.
- Writing to VTBIA or VSAR with MTPR causes the new state of the changed vector IPR to affect the execution of all subsequently issued vector instructions.
- Reading from VPSR with MFPR after writing to VPSR with MTPR causes the new state of VPSR (and VAER if cleared by VPSR<RST>) to affect the execution of subsequently issued vector instructions.

#### 10.7.4 Memory Synchronization Within the Vector Processor (VSYNC)

The vector processor may concurrently execute a number of vector memory instructions through the use of multiple load/store paths to memory. When it is necessary to synchronize the accesses of multiple vector memory instructions the MSYNC instruction can be used; however, there are cases for which this instruction does more than is needed. If it is known that only synchronization between the memory accesses of vector instructions is required, the VSYNC instruction is more efficient.

VSYNC orders the conflicting memory accesses of vector-memory instructions issued after VSYNC with those of vector-memory instructions issued before VSYNC. Specifically, VSYNC forces the access of a memory location by any subsequent vector-memory instruction to wait for (depend upon) the completion of all prior conflicting accesses of that location by previous vector-memory instructions.

VSYNC does not have any synchronizing effect between scalar and vector memory access instructions. VSYNC also has no synchronizing effect between vector load instructions because multiple load accesses cannot conflict. It also does not ensure that previous vector memory management exceptions are reported to the scalar processor.

### 10.7.5 Required Use of Memory Synchronization Instructions

Table 10–15 shows for all possible pairs of vector or scalar read and write operations to a common memory location, whether one of the scalar/vector memory synchronization instructions or the VSYNC instruction must be issued after the first reference and before the second. Since the MSYNC instruction also includes the VSYNC function, it can always be used instead of VSYNC.

In general, these rules apply to any sequence of instructions that access a common memory location, no matter how many other vector or scalar instructions are issued between the first instruction that accesses the common location and the second instruction that accesses the same location. For example, the following code sequence depicts a vector load followed by a scalar write operation to the same memory location. Between these two instructions are other scalar/vector instructions that do not access the common memory location. A scalar/vector memory synchronization instruction (MSYNC or VMAC) must be executed sometime after the vector read operation and before the scalar write operation to the common location. (Here MSYNC is shown.)

```
VLDL  A, #4, V0
      .
other scalar/vector instructions
that do not access A
      .
MSYNC Dst
MOVL  R0, A
```

In most cases, MSYNC is the preferred method for ensuring scalar/vector memory synchronization. However, there are special cases, usually encountered by an operating system, when VMAC is more appropriate.

Cases when scalar/vector memory synchronization is required are as follows:

- After a vector instruction that stores to memory and before a peripheral (I/O) data transfer of the stored location is initiated by an application program. This ensures that the value stored will be transferred to the output device. The application must ensure that this requirement is met by using MSYNC. Using VMAC in this case is not sufficient because unlike MSYNC, VMAC does not ensure that all previous vector memory instructions have successfully completed.
- After a vector instruction that stores to memory and before the associated scalar processor can execute a HALT instruction. This ensures that a read operation or modify operation by another processor will access the updated memory value. VMAC is the preferred method for this case.
- Before the vector processor state is saved as a result of power failure. A read or modify operation of the same memory must read the updated value (provided that the duration of the power failure does not exceed the maximum nonvolatile period of the main memory). Also, software is responsible for saving any pending vector processor exception status. VMAC is the preferred method for this case.
- Before a context switch. Software is responsible for ensuring that the vector processor has completed all its memory accesses before performing a context switch. Software is also responsible for saving any pending vector processor exception status. VMAC is the preferred method for this case.

## VAX Vector Architecture

### 10.7 Synchronization

The scalar/vector memory synchronization instructions are the only ones that guarantee that the memory operations of the vector and scalar processors are synchronized. Write operations to I/O space, changes in access mode, machine checks, interprocessor interrupts, execution of a HALT, REI, or interlocked instruction do not make the results of vector instructions that write to memory visible to the scalar processor, I/O subsystem, or other processors. Execution of a scalar/vector memory synchronization instruction must precede any of these mechanisms to ensure synchronization of all system components.

**Table 10–15 Possible Pairs of Read and Write Operations When Scalar/Vector Memory Synchronization (M) or VSYNC (V) Is Required Between Instructions That Reference the Same Memory Location**

| First Reference<br>Second Reference | Scalar<br>Scalar  | Scalar<br>Vector | Vector<br>Scalar | Vector<br>Vector |
|-------------------------------------|-------------------|------------------|------------------|------------------|
| <b>Operation Sequence</b>           |                   |                  |                  |                  |
| Read, Read                          | No <sup>1,2</sup> | No <sup>1</sup>  | No <sup>1</sup>  | No <sup>1</sup>  |
| Read, Write                         | No <sup>2</sup>   | No <sup>3</sup>  | M                | V <sup>5</sup>   |
| Write, Read                         | No <sup>2</sup>   | M <sup>4</sup>   | M                | V                |
| Write, Write                        | No <sup>2</sup>   | M <sup>4</sup>   | M                | V                |

<sup>1</sup>Scalar/vector memory synchronization or VSYNC is never required between two read accesses to a memory location.

<sup>2</sup>Scalar/vector memory synchronization is never required between two accesses by the VAX scalar processor to a memory location.

<sup>3</sup>The scalar read is synchronous and will have completed before a vector memory operation is issued.

<sup>4</sup>Although a scalar write operation is a synchronous instruction, scalar/vector memory synchronization is required to ensure that the written data is visible to the vector processor before the vector memory reference is executed.

<sup>5</sup>See Section 10.7.5.1 for the conditions when VSYNC is not required between a vector memory read/write pair.

#### 10.7.5.1 When VSYNC Is Not Required

There exist conditions when VSYNC is not required between conflicting vector memory accesses. A VSYNC is not required before a vector memory store instruction (VST/VSCAT) if, for each memory location to be accessed by the store, both of the following conditions are met:

- Each of the store's accesses to the location does not conflict with any access to the location by previously issued vector store instructions. Conflict is avoided in this case because one of the following events occurred:
  - The location is not shared.
  - All accesses to the location by previous store instructions were forced to complete by the issue of an MSYNC or VMAC.
- Each of the store's accesses to the location does not conflict with any access to the location by previously issued vector load (VLD/VGATH) instructions. Conflict is avoided in this case because one of the following events occurred:
  - The location is not shared.
  - All accesses to the location by previous load instructions were forced to complete by the issue of an MSYNC or VMAC.
  - Each of the store's accesses to the location depends on the completion (as seen by the vector processor) of all accesses to the location by previous LOAD instructions. (The examples immediately following demonstrate this concept.)

In all other cases of conflicting vector memory accesses, VSYNC is necessary to ensure correct results.

#### Examples Where VSYNC Is Not Required

In the following examples, VSYNC is not required because both of the previous conditions have been met for each location accessed by the store instruction:

## VAX Vector Architecture

### 10.7 Synchronization

1. VLDL           A, #4, V0  
   VSTL          V0, A, #4
  
2. VLDL           A, #4, V0  
   VSSUBL        R0, V0, V1  
   VSTL          V1, A, #4
  
3. VLDL/0        A, #4, V0  
   VSMULL/0     #3, V0, V0  
   VLDL/1        A, #4, V1  
   VVMULL/1     V1, V1, V1  
   VVMERGE/1    V1, V0, V2  
   VSTL          V2, A, #4
  
4. VLDL           A, #4, V0  
   VSGTRF        #0, V0  
   VLDL/1        B, #4, V1  
   VLDL/0        C, #4, V2  
   VVMERGE/0    V2, V1, V3  
   VSTL          V3, A, #4

#### Examples Where VSYNC Is Required

In the following examples, VSYNC is required before the vector memory store instruction:

1. VLDL/1        A, #4, V0  
   VSLSSL        #0, V1  
   VSYNC  
   VSTL/1        V1, A, #4

If the VSYNC is not included, V0 could contain incorrect data at the end of the sequence since the vector processor is allowed to begin the VSTL before the VLDL is finished. This occurs because there is no dependence between the VMR value used by the VLDL and the VSTL.

2. VLDL           A, #4, V0  
   VVMERGE/0    V0, V1, V1  
   VSYNC  
   VSTL          V1, A, #4

Unless the programmer can ensure that the VMR mask being used by the VVMERGE will force the access of each location by the VSTL to depend on the access to that location by the VLDL, a VSYNC is required. Note that in general, when masked operations provide a conditional path of dependence between conflicting memory accesses, a VSYNC is usually necessary to ensure correct results.

```

3. VSTL      V1, A, #4
   MTVLR    #32
   VSYNC
   VLDL     A+128, #4, V2

```

In this example, the VSTL writes locations A to A+255 and the VLDL reads locations A+128 to A+255. Without the VSYNC, the vector processor is allowed to start reading locations A+128 to A+255 for the VLDL before the vector processor completes (or even starts) writing locations A+128 to A+255 for the VSTL. Consequently, V2[0:31] will not contain V1[32:63], which is the intended result. Note that the rules on when VSYNC is not required (found in Section 10.7.5.1) only apply to waiving the use of VSYNC prior to VST/VSCAT instructions.

```

4. VGATHL   A, V2, V0      ; let at least two elements
                           ; of V2 be equal
   VVMULL   V9, V0, V1
   VSYNC
   VSCATL   V1, A, V2

```

The VSYNC is needed in this example because the VSCATL may store elements of V1 into a common location before the VGATHL has finished loading that location into all the appropriate elements of V0. As a result, elements of V0 fetched from the same location may be unequal. Suppose in the example that V2[0] = V2[63] = 0 and that the original value of location A before the sequence starts is X. Then it is possible without the VSYNC that V0[63] = X\*V9[0] and that (A)= V1[63] = V9[63]\*V9[0]\*X after the sequence completes.

```

5. VLDL     A, #0, V0
   VVMULL   V9, V0, V1
   VSYNC
   VSTL     V1, A, #0

```

The VSYNC is needed in this example because the VSTL may store elements of V1 into A before the VLDL has finished loading all elements of V0 from A. As a result, the elements of V0 may be unequal and so produce incorrect results.

## 10.8 Memory Management

The vector processor may include its own translation buffer and maintain its own copies of SBR, SLR, SPTEP, P0BR, P0LR, P1BR, and P1LR as a group, or may use the scalar processor's memory management unit. Hardware implementations must ensure that MTPR to these registers update the copy retained by the vector processor. Changes to P0BR, P0LR, P1BR, and P1LR due to a LDPCTX do not update the copies in the vector processor. Before software enables the vector processor again, explicit MTPRs to P0BR, P0LR, P1BR, and P1LR are required to guarantee correct operation.

An MTPR to TBIS must also invalidate the corresponding TB entry in the vector processor, and an MTPR to TBIA must also invalidate the entire TB in the vector processor. However, the vector TB is not invalidated by a LDPCTX instruction. Software can use an MTPR to the Vector TB Invalidate All (VTBIA) register to invalidate only the vector TB. An MTPR to VTBIA results in no operation on a processor that uses a common TB for the scalar and vector processors.

## VAX Vector Architecture

### 10.8 Memory Management

Updates to memory management registers and invalidates of translation buffer entries in the vector processor take place even when the vector processor is disabled (VPSR<VEN> is clear). However, the vector processor may load translation buffer entries only when the vector processor is executing a vector memory access instruction.

The vector processor implements the modify-fault option if its scalar processor implements the virtual-machine option.

Vector memory access instructions must not be used to read or write page tables. If a vector instruction is used to read or write page tables, the results are UNPREDICTABLE.

Vector instructions are not allowed to reference I/O space. If a vector instruction references I/O space, the results are UNPREDICTABLE.

Issuing vector instructions with memory management disabled causes the operation of the vector processor to be UNDEFINED. Disabling memory management when the vector processor is busy (VPSR<BSY> is set) also causes the operation of the vector processor to be UNDEFINED.

### 10.9 Hardware Errors

A vector processor implementation may experience error conditions (such as chip malfunctions, parity errors, or bus errors) that prevent it from executing and completing instructions and from which it cannot recover through its own means. Such errors are termed hardware errors and may occur at anytime, even when the vector processor is already disabled. Vector processor hardware errors do not normally halt the scalar processor.

At some point after the error condition occurs, the vector processor reports the error to the scalar processor. The reporting may be accomplished through a machine check; or by disabling the vector processor, setting VPSR<IMP>, and generating a vector processor disabled fault when the next vector instruction is issued. After the error is reported, the appropriate software handler will be invoked to diagnose the vector processor and to determine the severity of the hardware error and whether the vector processor can be restarted.

During execution, software may wish to force the reporting of hardware errors encountered by previous vector instructions before issuing further ones. This can be accomplished by reading the VMAC internal processor register (IPR) and by waiting for VPSR<BSY> to become clear.

An MFPR from VMAC ensures that all pending vector memory instructions have finished or are suspended by an asynchronous memory management exception, and that all vector-processor hardware errors encountered by these instructions are reported by the time the MFPR completes. Errors are handled as follows:

- If the errors are reported by machine check, then the exception is taken either upon the VMAC itself, or upon the instruction immediately following the VMAC.
- If the errors are reported through VPSR<IMP>, the vector processor sets VPSR<IMP> and disables itself by the time the scalar processor completes VMAC. Subsequently, a vector processor disabled fault will occur when the next vector instruction is issued. A read of VPSR immediately after the VMAC completes will find the vector processor disabled and VPSR<IMP> set.

Waiting for VPSR<BSY> to become clear before issuing further instructions ensures that all previous non-memory-access instructions have been finished or are suspended by an asynchronous memory management exception, and that all vector-processor hardware errors encountered by these instructions are reported by the time VPSR<BSY> becomes clear. Errors are handled as follows:

- If the errors are reported by machine check, then the exception is taken either upon the first instruction during which the new state of VPSR<BSY> becomes visible to the scalar processor or upon the instruction immediately thereafter.
- If the errors are reported through VPSR<IMP>, the vector processor sets VPSR<IMP> and disables itself by the time it clears VPSR<BSY>. Subsequently, a vector processor disabled fault will occur when the next vector instruction is issued. The first MFPR instruction that reads VPSR<BSY> as clear will also read VPSR<VEN> as clear and VPSR<IMP> as set.

VMAC does not ensure that hardware errors encountered by pending non-memory-access instructions will be reported. Waiting for VPSR<BSY> to become clear does not ensure that vector-processor hardware errors encountered by vector memory instructions are reported.

Software can force the reporting of hardware errors encountered during the execution of previous vector instructions (both memory and non-memory) by waiting for VPSR<BSY> to become clear and then by issuing an MFPR from VMAC. This technique can be used during scalar context switching to cause hardware errors resulting from the execution of vector instructions for the current process to be reported before that process is context-switched.

## 10.10 Vector Memory Access Instructions

There are alignment, stride, address specifier context, and access mode considerations for the vector memory access instructions.

### 10.10.1 Alignment Considerations

Vector memory access instructions require their vector operands to be naturally aligned in memory. Longwords must be aligned on longword boundaries. Quadwords must be aligned on quadword boundaries. If any vector element is not naturally aligned in memory, an access control violation occurs. For further details, see Section 10.6.1, Vector Memory Management Exception Handling.

The scalar operands need not be naturally aligned in memory.

### 10.10.2 Stride Considerations

A vector's stride is defined as the number of memory locations (bytes) between the starting address of consecutive vector elements. A contiguous vector that has longword elements has a stride of four; a contiguous vector that has quadword elements has a stride of eight.

### 10.10.3 Context of Address Specifiers

The base address specifier used by the vector memory access instructions is of byte context, regardless of the data type. Arrays are addressed as byte strings. Index values in array specifiers are multiplied by one, and the amount of autoincrement or autodecrement, when either of these modes is used, is one.

## **VAX Vector Architecture**

### **10.10 Vector Memory Access Instructions**

#### **10.10.4 Access Mode**

A vector memory access instruction is executed using the access mode in effect when the instruction is issued by the scalar processor.

#### **10.10.5 Memory Instructions**

This section describes VAX vector architecture memory instructions.

## VLD

Load Memory Data into Vector Register

### Format

VLDL  $[/M[0|1]]$  base, stride, Vc  
 VLDQ  $[/M[0|1]]$  base, stride, Vc

### Architecture

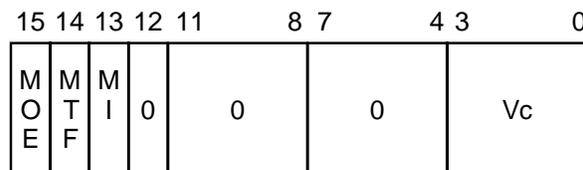
#### Format

*opcode cntrl.rw, base.ab, stride.rl*

#### Opcodes

34FD VLDL Load Longword Vector from Memory to Vector Register  
 36FD VLDQ Load Quadword Vector from Memory to Vector Register

#### Vector Control Word



ZK-1457A-GE

#### Exceptions

access control violation  
 translation not valid  
 vector alignment

### Description

The source operand vector is fetched from memory and is written to vector destination register Vc. The length of the vector is specified by VLR. The virtual address of the source vector is computed using the base address and the stride. The address of element *i* ( $0 \text{ LEQU } i \text{ LEQU } (\text{VLR}-1)$ ) is computed as  $\{\text{base} + \{i * \text{stride}\}\}$ . The stride can be positive, negative, or zero.

In VLDL, bits <31:0> of each destination vector element receive the memory data and bits <63:32> are UNPREDICTABLE.

If any vector element operated upon is not naturally aligned in memory, a vector alignment exception occurs.

The results of VLD are unaffected by the setting of *cntrl<MI>*. For more details about the use of *cntrl<MI>*, see Section 10.3.3, Modify Intent bit.

If the addressing mode of the BASE operand is immediate, the results of the instruction are UNPREDICTABLE.

## VAX Instruction Set

### VLD

An implementation may load the elements of the vector in any order, and more than once. When a vector processor memory management exception occurs, the contents of the destination vector elements are UNPREDICTABLE.

## VGATH

Gather Memory Data into Vector Register

### Format

VGATHL  $[/M[0|1]]$  base, Vb, Vc

VGATHQ  $[/M[0|1]]$  base, Vb, Vc

### Architecture

#### Format

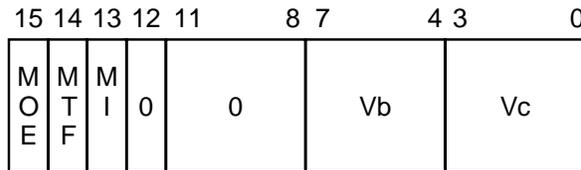
*opcode* *cntrl.rw, base.ab*

#### Opcodes

35FD VGATHL Gather Longword Vector from Memory to Vector Register

37FD VGATHQ Gather Quadword Vector from Memory to Vector Register

#### vector\_control\_word



ZK-1458A-GE

#### Exceptions

access control violation  
translation not valid  
vector alignment

### Description

The source operand vector is fetched from memory and is written to vector destination register Vc. The length of the vector is specified by VLR. The virtual address of the vector is computed using the base address and the 32-bit offsets in vector register Vb. The address of element *i* ( $0 \text{ LEQU } i \text{ LEQU } (\text{VLR}-1)$ ) is computed as  $\{\text{base}+\text{Vb}[i]\}$ . The 32-bit offset can be positive, negative, or zero.

In VGATHL, bits <31:0> of each destination vector element receive the memory data and bits <63:32> are UNPREDICTABLE.

If any vector element operated upon is not naturally aligned in memory, a vector alignment exception occurs.

The results of VGATH are unaffected by the setting of *cntrl*<MI>. For more details about the use of *cntrl*<MI>, see Section 10.3.3, Modify Intent bit.

If the addressing mode of the BASE operand is immediate, the results of the instruction are UNPREDICTABLE.

## VAX Instruction Set

### VGATH

An implementation may load the elements of the vector in any order, and more than once. When a vector processor memory management exception occurs, the contents of the destination vector elements are UNPREDICTABLE.

If the same vector register is used as both source and destination, the result of the VGATH is UNPREDICTABLE.

## VST

Store Vector Register Data into Memory

### Format

VSTL [0|1] Vc, base, stride  
VSTQ [0|1] Vc, base, stride

### Architecture

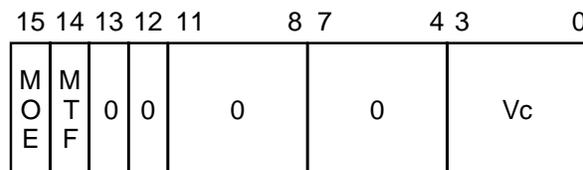
#### Format

*opcode* *cntrl.rw*, *base.ab*, *stride.rl*

#### Opcodes

9CFD VSTL Store Longword Vector from Vector Register to Memory  
9EFD VSTQ Store Quadword Vector from Vector Register to Memory

#### vector\_control\_word



ZK-1459A-GE

#### Exceptions

- access control violation
- translation not valid
- vector alignment
- modify

### Description

The source operand in vector register Vc is written to memory. The length of the vector is specified by the Vector Length Register (VLR). The virtual address of the destination vector is computed using the base address and the stride. The address of element *i* ( $0 \leq i < \text{VLR}$ ) is computed as  $\{\text{base} + \{i * \text{stride}\}\}$ . The stride can be positive, negative, or zero.

If any vector element operated upon is not naturally aligned in memory, a vector alignment exception occurs.

For a nonzero stride value, an implementation may store the vector elements in parallel; therefore the order in which these elements are stored is UNPREDICTABLE. Furthermore, if the nonzero stride causes result locations in memory to overlap, then the values stored in the overlapping result locations are also UNPREDICTABLE.

For a stride value of zero, the highest numbered register element destined for the single memory location becomes the final value of that location.

## VAX Instruction Set

### VST

When a vector processor memory management exception occurs, it is UNPREDICTABLE whether the vector processor writes any result location for which an exception did not occur. If the fault condition can be eliminated by software and the instruction restarted, then the vector processor will ensure that all destination locations are written.

If the destination vector overlaps the vector instruction control word, base, or stride operand, the result of the instruction is UNPREDICTABLE.

If the addressing mode of the BASE operand is immediate, the results of the instruction are UNPREDICTABLE.

## VSCAT

Scatter Vector Register Data into Memory

### Format

VSCATL [0|1] Vc, base, Vb

VSCATQ [0|1] Vc, base, Vb

### Architecture

#### Format

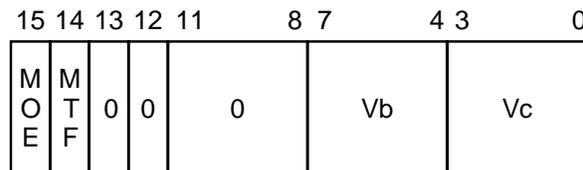
*opcode* *cntrl.rw, base.ab*

#### Opcodes

9DFD VSCATL Scatter Longword Vector from Vector Register to Memory

9FFD VSCATQ Scatter Quadword Vector from Vector Register to Memory

#### vector\_control\_word



ZK-1460A-GE

#### Exceptions

- access control violation
- translation not valid
- vector alignment
- modify

### Description

The source vector operand Vc is written to memory. The length of the vector is specified by the Vector Length Register (VLR) register. The virtual address of the destination vector is computed using the base address operand and the 32-bit offsets in vector register Vb. The address of element i (0 LEQU i LEQU (VLR-1)) is computed as {base+Vb[i]}. The 32-bit offset can be positive, negative, or zero.

If any vector element operated upon is not naturally aligned in memory, a vector alignment exception occurs.

An implementation may store the vector elements in parallel; therefore, the order in which elements are stored to different memory locations is UNPREDICTABLE. In the case where multiple elements are destined for the same memory location, the highest numbered element among them becomes the final value of that location.

## VAX Instruction Set

### VSCAT

When a vector processor memory management exception occurs, it is UNPREDICTABLE whether the vector processor writes any result location for which an exception did not occur. If the fault condition can be eliminated by software and the instruction restarted, then the vector processor will ensure that all destination locations are written.

If the destination vector overlaps the vector instruction control word or base operand, the result of the instruction is UNPREDICTABLE.

If the addressing mode of the BASE operand is immediate, the results of the instruction are UNPREDICTABLE.

---

## 10.11 Vector Integer Instructions

This section describes VAX vector architecture integer instructions.

## VADDL

Vector Integer Add

### Format

vector + vector:

VVADDL [0|1] Va, Vb, Vc

scalar + vector:

VSADDL [0|1] scalar, Vb, Vc

### Architecture

#### Format

*vector + vector:* opcode cntrl.rw

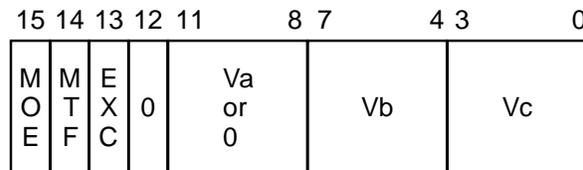
*scalar + vector:* opcode cntrl.rw, addend.rl

#### Opcodes

80FD VVADDL Vector Vector Add Longword

81FD VSADDL Vector Scalar Add Longword

#### vector\_control\_word



ZK-1461A-GE

#### Exceptions

integer overflow

### Description

The scalar addend or Va operand is added, elementwise, to vector register Vb and the 32-bit sum is written to vector register Vc. Only bits <31:0> of each vector element participate in the operation. Bits <63:32> of the elements of vector register Vc are UNPREDICTABLE. The length of the vector is specified by the Vector Length Register (VLR).

If integer overflow is detected and cntrl<EXC> is set, the exception type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER) and the vector operation is allowed to complete. On integer overflow, the low-order 32 bits of the true result are stored in the destination element.

## VCMPL

Vector Integer Compare

### Format

vector–vector:

|        |   |       |        |
|--------|---|-------|--------|
| VVGTRL | } | [0 1] | Va, Vb |
| VVEQLL |   |       |        |
| VVLSSL |   |       |        |
| VVLEQL |   |       |        |
| VVNEQL |   |       |        |
| VVGEQL |   |       |        |

scalar–vector:

|        |   |       |         |
|--------|---|-------|---------|
| VSGTRL | } | [0 1] | src, Vb |
| VSEQLL |   |       |         |
| VSLSSL |   |       |         |
| VSLEQL |   |       |         |
| VSNEQL |   |       |         |
| VSGEQL |   |       |         |

### Architecture

#### Format

*vector–vector:*    *opcode*    *cntrl.rw*

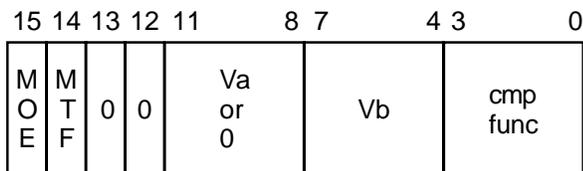
*scalar–vector:*    *opcode*    *cntrl.rw, src.rl*

#### Opcodes

C0FD    VVCMPL    Vector Vector Compare Longword

C1FD    VSCMPL    Vector Scalar Compare Longword

#### vector\_control\_word



ZK-1462A-GE

The condition being tested is determined by `cntrl<2:0>`, as follows:

| Value of <code>cntrl&lt;2:0&gt;</code> | Meaning               |
|--|-----------------------|
| 0                                      | Greater than          |
| 1                                      | Equal                 |
| 2                                      | Less than             |
| 3                                      | Reserved <sup>1</sup> |
| 4                                      | Less than or equal    |
| 5                                      | Not equal             |
| 6                                      | Greater than or equal |
| 7                                      | Reserved <sup>1</sup> |

<sup>1</sup>Vector integer compare instructions that specify reserved values of `cntrl<2:0>` produce UNPREDICTABLE results.

## Description

The scalar or `Va` operand is compared, elementwise, with vector register `Vb`. The length of the vector is specified by the Vector Length Register (VLR). For each element comparison, if the specified relationship is true, the Vector Mask Register bit (`VMR<i>`) corresponding to the vector element is set to one; otherwise, it is cleared. If `cntrl<MOE>` is set, `VMR` bits corresponding to elements that do not match `cntrl<MTF>` are left unchanged. `VMR` bits beyond the vector length are left unchanged. Only bits `<31:0>` of each vector element participate in the operation.

## VMULL

Vector Integer Multiply

### Format

vector \* vector:

VVMULL [V[0|1]] Va, Vb, Vc

scalar \* vector:

VSMULL [V[0|1]] scalar, Vb, Vc

### Architecture

#### Format

*vector \* vector:* opcode cntrl.rw

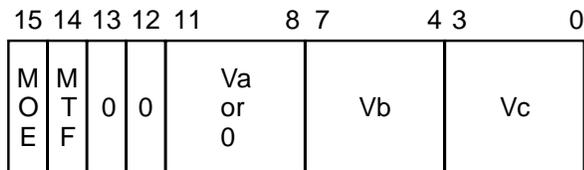
*scalar \* vector:* opcode cntrl.rw, mulr.rl

#### Opcodes

A0FD VVMULL Vector Vector Multiply Longword

A1FD VSMULL Vector Scalar Multiply Longword

#### vector\_control\_word



ZK-1463A-GE

#### Exceptions

integer overflow

### Description

The scalar multiplier or vector operand Va is multiplied, elementwise, by vector operand Vb and the least significant 32 bits of the signed 64-bit product are written to vector register Vc. Only bits <31:0> of each vector element participate in the operation. Bits <63:32> of the elements of vector register Vc are UNPREDICTABLE. The length of the vector is specified by the Vector Length Register (VLR).

If integer overflow is detected and cntrl<EXC> is set, the exception condition type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER) and the vector operation is allowed to complete. On integer overflow, the low-order 32 bits of the true result are stored in the destination element.

## VSUBL

Vector Integer Subtract

### Format

vector–vector:

VVSUBL [*V*[0|1]] Va, Vb, Vc

scalar–vector:

VSSUBL [*V*[0|1]] scalar, Vb, Vc

### Architecture

#### Format

*vector–vector:* opcode cntrl.rw

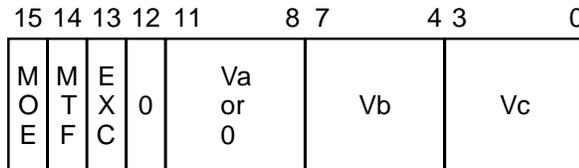
*scalar–vector:* opcode cntrl.rw, min.rl

#### Opcodes

88FD VVSUBL Vector Vector Subtract Longword

89FD VSSUBL Vector Scalar Subtract Longword

#### vector\_control\_word



ZK-1461A-GE

#### Exceptions

integer overflow

### Description

The vector operand Vb is subtracted, elementwise, from the scalar minuend or vector operand Va. The 32-bit difference is written to vector register Vc. Only bits <31:0> of each vector element participate in the operation. Bits <63:32> of the elements of vector register Vc are UNPREDICTABLE. The length of the vector is specified by the Vector Length Register (VLR).

If integer overflow is detected and cntrl<EXC> is set, the exception condition type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER) and the vector operation is allowed to complete. On integer overflow, the low-order 32 bits of the true result are stored in the destination element.

## 10.12 Vector Logical and Shift Instructions

This section describes VAX vector architecture logical and shift instructions.

## VBIC, VBIS, and VXOR

Vector Logical Functions

### Format

vector op vector:

$$\left\{ \begin{array}{l} \text{VVBISL} \\ \text{VVXORL} \\ \text{VVBICL} \end{array} \right\} [V[0|1]] \quad Va, Vb, Vc$$

vector op scalar:

$$\left\{ \begin{array}{l} \text{VSBISL} \\ \text{VSXORL} \\ \text{VSBICL} \end{array} \right\} [V[0|1]] \quad \text{scalar}, Vb, Vc$$

### Architecture

#### Format

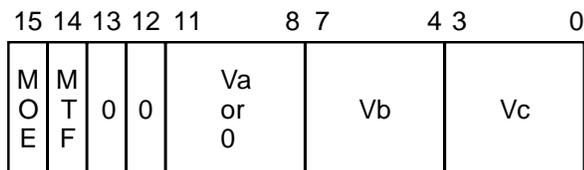
*vector op vector:*    *opcode*    *cntrl.rw*

*vector op scalar:*    *opcode*    *cntrl.rw, src.rl*

#### Opcodes

|      |        |                                     |
|------|--------|-------------------------------------|
| C8FD | VVBISL | Vector Vector Bit Set Longword      |
| E8FD | VVXORL | Vector Vector Exclusive-OR Longword |
| CCFD | VVBICL | Vector Vector Bit Clear Longword    |
| C9FD | VSBISL | Vector Scalar Bit Set Longword      |
| E9FD | VSXORL | Vector Scalar Exclusive-OR Longword |
| CDFD | VSBICL | Vector Scalar Bit Clear Longword    |

#### vector\_control\_word



ZK-1463A-GE

#### Exceptions

None.

## **Description**

The scalar src or vector operand Va is combined, elementwise, using the specified Boolean function, with vector register Vb and the result is written to vector register Vc. Only bits <31:0> of each vector element participate in the operation. Bits <63:32> of the elements of Vb are written into bits <63:32> of the corresponding elements of Vc. The length of the vector is specified by the Vector Length Register (VLR).

# VAX Instruction Set

## VSL

### VSL

Vector Shift Logical

#### Format

vector shift count:

$$\left\{ \begin{array}{l} \text{VVSRL} \\ \text{VVSLL} \end{array} \right\} [V[0|1]] \quad Va, Vb, Vc$$

scalar shift count:

$$\left\{ \begin{array}{l} \text{VSSRL} \\ \text{VSSLL} \end{array} \right\} [V[0|1]] \quad cnt, Vb, Vc$$

#### Architecture

##### Format

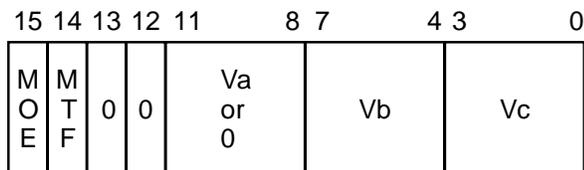
*vector shift count:*    *opcode*    *cntrl.rw*

*scalar shift count:*    *opcode*    *cntrl.rw, cnt.rl*

##### Opcodes

|      |       |  |
|------|-------|--|
| E0FD | VVSRL | Vector Vector Shift Right Logical Longword |
| E4FD | VVSLL | Vector Vector Shift Left Logical Longword  |
| E1FD | VSSRL | Vector Scalar Shift Right Logical Longword |
| E5FD | VSSLL | Vector Scalar Shift Left Logical Longword  |

##### vector\_control\_word



ZK-1463A-GE

##### Exceptions

None.

#### Description

Each element in vector register Vb is shifted logically left or right 0 to 31 bits as specified by a scalar count operand or vector register Va. The shifted results are written to vector register Vc. Zero bits are propagated into the vacated bit positions. Only bits <4:0> of the count operand and bits <31:0> of each Vb element participate in the operation. Bits <63:32> of the elements of vector register Vc are UNPREDICTABLE. The length of the vector is specified by the Vector Length Register (VLR).

## 10.13 Vector Floating-Point Instructions

The VAX vector architecture provides instructions for operating on F\_floating, D\_floating, and G\_floating operand formats. The floating-point arithmetic instructions are add, subtract, compare, multiply, and divide. Data conversion instructions are provided to convert operands between D\_floating, G\_floating, F\_floating, and longword integer.

Rounding is performed using standard VAX rounding rules. The accuracy of the vector floating-point instructions matches that of the scalar floating-point instructions. Refer to the section on floating-point instructions in the *VAX Architecture Reference Manual* for more information.

---

### 10.13.1 Vector Floating-Point Exception Conditions

All vector floating-point exception conditions occur asynchronously with respect to the scalar processor. These exception conditions do not interrupt the scalar processor. If the exception condition is enabled, then the exception condition type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER), and a reserved operand in the format of the instruction's data type is written into the destination register element. Encoded in this reserved operand is the exception condition type. After recording the exception and writing the appropriate result into the destination register element, the instruction encountering the exception continues executing to completion.

If a vector convert floating to integer instruction encounters a source element that is a reserved operand, an UNPREDICTABLE result rather than a reserved operand is written into the destination register element.

Figure 10–13 shows the encoding of the reserved operand that is written for vector floating-point exceptions. Consistent with the definition of a reserved operand, the sign bit (bit <15>) is one and the exponent (bits <14:7> for F\_floating and D\_floating, and bits <14:4> for G\_floating) is zero. When the reserved operand is written in F\_floating or D\_floating format, bits <6:4> are also zero. The exception condition type (ETYPE) is encoded in bits <3:0>, as shown in Table 10–16. If a reserved operand is divided by zero, both ETYPE bits may be set. The state of all other bits in the result (denoted by shading) is UNPREDICTABLE.

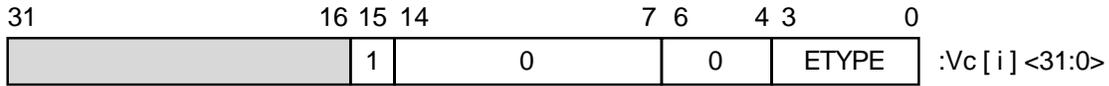
If the floating underflow exception condition is suppressed by `cntrl<EXC>`, a zero result is written to the destination register element and no further action is taken. Floating overflow, floating divide by zero, and floating reserved operand are always enabled.

# VAX Instruction Set

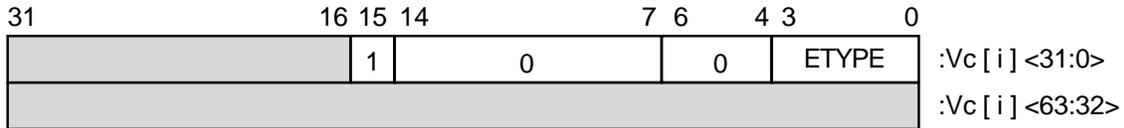
## 10.13 Vector Floating-Point Instructions

Figure 10–13 Encoding of the Reserved Operand

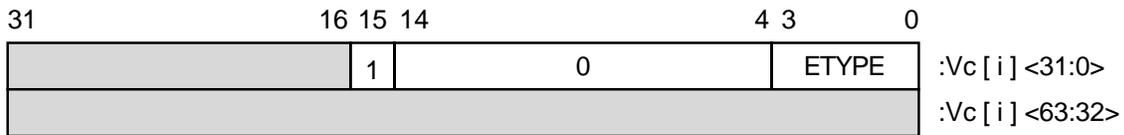
a. F\_floating



b. D\_floating



c. G\_floating



ZK-1464A-GE

Table 10–16 Encoding of the Exception Condition Type (ETYPE)

| Bit | Exception Condition Type  |
|-----|---------------------------|
| <0> | Floating underflow        |
| <1> | Floating divide by zero   |
| <2> | Floating reserved operand |
| <3> | Floating overflow         |

### 10.13.2 Floating-Point Instructions

This section describes VAX vector architecture floating-point instructions.

## VADD

Vector Floating Add

### Format

vector + vector:

$$\left\{ \begin{array}{l} \text{VVADDF} \\ \text{VVADDD} \\ \text{VVADDG} \end{array} \right\} [\text{U}[0|1]] \quad \text{Va, Vb, Vc}$$

scalar + vector:

$$\left\{ \begin{array}{l} \text{VSADDF} \\ \text{VSADDD} \\ \text{VSADDG} \end{array} \right\} [\text{U}[0|1]] \quad \text{scalar, Vb, Vc}$$

### Architecture

#### Format

vector + vector:

*opcode cntrl.rw*

scalar + vector (F\_floating):

*opcode cntrl.rw, addend.rl*

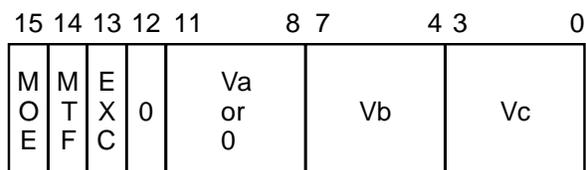
scalar + vector (D\_ and G\_floating):

*opcode cntrl.rw, addend.rq*

#### Opcodes

|      |        |                              |
|------|--------|------------------------------|
| 84FD | VVADDF | Vector Vector Add F_Floating |
| 85FD | VSADDF | Vector Scalar Add F_Floating |
| 86FD | VVADDD | Vector Vector Add D_Floating |
| 87FD | VSADDD | Vector Scalar Add D_Floating |
| 82FD | VVADDG | Vector Vector Add G_Floating |
| 83FD | VSADDG | Vector Scalar Add G_Floating |

#### vector\_control\_word



ZK-1461A-GE

#### Exceptions

floating overflow  
floating reserved operand  
floating underflow

## VAX Instruction Set

### VADD

#### Description

The source addend or vector operand  $V_a$  is added, elementwise, to vector register  $V_b$  and the sum is written to vector register  $V_c$ . The length of the vector is specified by the Vector Length Register (VLR).

In  $V_xADDF$ , only bits <31:0> of each vector element participate in the operation. Bits <63:32> of the destination vector elements are UNPREDICTABLE.

If a floating underflow occurs when  $cntrl<EXC>$  is set or if a floating overflow or floating reserved operand occurs, an encoded reserved operand is stored as the result and the exception condition type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER). The vector operation is then allowed to complete. If  $cntrl<EXC>$  is clear, zero is written to the destination element when an exponent underflow occurs and no other action is taken.

## VCMP

Vector Floating Compare

### Format

vector–vector:

|  |                      |
|--|----------------------|
| {<br>VVGTRF<br>VVGTRD<br>VVGTRG<br>VVEQLF<br>VVEQLD<br>VVEQLG<br>VVLSSF<br>VVLSSD<br>VVLSSG<br>VVLEQF<br>VVLEQD<br>VVLEQG<br>VVNEQF<br>VVNEQD<br>VVNEQG<br>VVGEQF<br>VVGEQD<br>VVGEQG<br>} | [U[0   1]]    Va, Vb |
|--|----------------------|

scalar–vector:

|  |                       |
|--|-----------------------|
| {<br>VSGTRF<br>VSGTRD<br>VSGTRG<br>VSEQLF<br>VSEQLD<br>VSEQLG<br>VSLSSF<br>VSLSSD<br>VSLSSG<br>VSLEQF<br>VSLEQD<br>VSLEQG<br>VSNEQF<br>VSNEQD<br>VSNEQG<br>VSGEQF<br>VSGEQD<br>VSGEQG<br>} | [U[0   1]]    src, Vb |
|--|-----------------------|

# VAX Instruction Set

## VCMP

### Architecture

#### Format

vector–vector:

*opcode cntrl.rw*

scalar–vector (F\_floating):

*opcode cntrl.rw, src.rl*

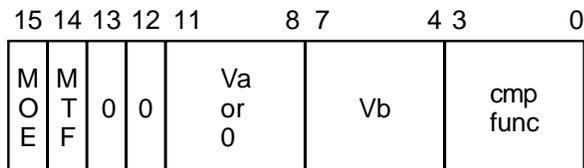
scalar–vector (D\_ and G\_floating):

*opcode cntrl.rw, src.rq*

#### Opcodes

|      |         |                                  |
|------|---------|----------------------------------|
| C4FD | VVCMPPF | Vector Vector Compare F_floating |
| C5FD | VSCMPF  | Vector Scalar Compare F_floating |
| C6FD | VVCMPPD | Vector Vector Compare D_floating |
| C7FD | VSCMPD  | Vector Scalar Compare D_floating |
| C2FD | VVCMPPG | Vector Vector Compare G_floating |
| C3FD | VSCMPG  | Vector Scalar Compare G_floating |

#### vector\_control\_word



ZK-1462A-GE

The condition being tested is determined by `cntrl<2:0>`, as follows:

| Value of <code>cntrl&lt;2:0&gt;</code> | Meaning               |
|--|-----------------------|
| 0                                      | Greater than          |
| 1                                      | Equal                 |
| 2                                      | Less than             |
| 3                                      | Reserved <sup>1</sup> |
| 4                                      | Less than or equal    |
| 5                                      | Not equal             |
| 6                                      | Greater than or equal |
| 7                                      | Reserved <sup>1</sup> |

<sup>1</sup>Vector integer compare instructions that specify reserved values of `cntrl<2:0>` produce UNPREDICTABLE results.

---

**Note**

---

Cntrl<3> should be zero; if it is set, the results of the instruction are UNPREDICTABLE.

---

**Exceptions**

floating reserved operand

**Description**

The scalar or vector operand  $V_a$  is compared, elementwise, with vector register  $V_b$ . The length of the vector is specified by the Vector Length Register (VLR). For each element comparison, if the specified relationship is true, the Vector Mask Register bit (VMR< $i$ >) corresponding to the vector element is set to one, otherwise it is cleared. If cntrl<MOE> is set, VMR bits corresponding to elements that do not match cntrl<MTF> are left unchanged. VMR bits beyond the vector length are left unchanged. If an element being compared is a reserved operand, VMR< $i$ > is UNPREDICTABLE. In VxCMPF, only bits <31:0> of each vector element participate in the operation.

If a floating reserved operand exception occurs, the exception condition type is recorded in the Vector Arithmetic Exception Register (VAER) and the vector operation is allowed to complete.

Note that for this instruction, no bits are set in the VAER destination register mask when an exception occurs.

## VVCVT

Vector Convert

### Format

|          |   |          |        |
|----------|---|----------|--------|
| VVCVTLF  | } | [U[0 1]] | Vb, Vc |
| VVCVTLD  |   |          |        |
| VVCVTLG  |   |          |        |
| VVCVTFL  |   |          |        |
| VVCVTRFL |   |          |        |
| VVCVTFD  |   |          |        |
| VVCVTFG  |   |          |        |
| VVCVTDL  |   |          |        |
| VVCVTDF  |   |          |        |
| VVCVTRDL |   |          |        |
| VVCVTGL  |   |          |        |
| VVCVTGF  |   |          |        |
| VVCVTRGL |   |          |        |

### Architecture

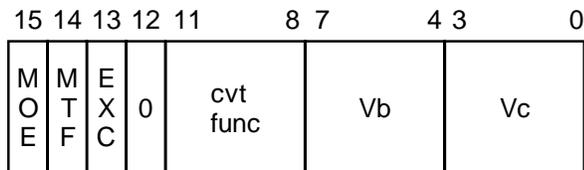
#### Format

*opcode* *cntrl.rw*

#### Opcodes

ECFD      VVCVT      Vector Convert

#### vector\_control\_word



ZK-1465A-GE

Cntrl<11:8> specifies the conversion to be performed, as follows:

| cntrl<11:8> | Meaning  |
|-------------|--|
| 1 1 1 1     | CVTRGL (Convert Rounded G_Floating to Longword)  |
| 1 1 1 0     | Reserved <sup>1</sup>                            |
| 1 1 0 1     | CVTGF (Convert Rounded G_Floating to F_Floating) |
| 1 1 0 0     | CVTGL (Convert Truncated G_Floating to Longword) |
| 1 0 1 1     | Reserved <sup>1</sup>                            |
| 1 0 1 0     | CVTRD (Convert Rounded D_Floating to Longword)   |

<sup>1</sup>Vector convert instructions that specify reserved values of cntrl<11:8> produce UNPREDICTABLE results.

| cntrl<11:8> | Meaning  |
|-------------|--|
| 1 0 0 1     | CVTDF (Convert Rounded D_Floating to F_Floating) |
| 1 0 0 0     | CVTDL (Convert Truncated D_Floating to Longword) |
| 0 1 1 1     | CVTFG (Convert F_Floating to G_Floating (exact)) |
| 0 1 1 0     | CVTFD (Convert F_Floating to D_Floating (exact)) |
| 0 1 0 1     | CVTRF (Convert Rounded F_Floating to Longword)   |
| 0 1 0 0     | CVTFL (Convert Truncated F_Floating to Longword) |
| 0 0 1 1     | CVTLG (Convert Longword to G_Floating (exact))   |
| 0 0 1 0     | CVTLD (Convert Longword to D_Floating (exact))   |
| 0 0 0 1     | CVTLF (Convert Rounded Longword to F_Floating)   |
| 0 0 0 0     | Reserved <sup>1</sup>                            |

<sup>1</sup>Vector convert instructions that specify reserved values of cntrl<11:8> produce UNPREDICTABLE results.

### Exceptions

- floating overflow
- floating reserved operand
- floating underflow
- integer overflow

## Description

The vector elements in vector register Vb are converted and results are written to vector register Vc. Cntrl<11:8> specifies the conversion to be performed. The length of the vector is specified by the Vector Length Register (VLR). Bits <63:32> of Vc are UNPREDICTABLE for instructions that convert from D\_floating or G\_floating to F\_floating or longword. When CVTRGL, CVTRDL, and CVTRFL round, the rounding is done in sign magnitude, before conversion to two's complement.

If an integer overflow occurs when cntrl<EXC> is set, the low-order 32 bits of the true result are written to the destination element as the result, and the exception condition type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER). The vector operation is then allowed to complete. If integer overflow occurs when cntrl<EXC> is clear, the low-order 32 bits of the true result are written to the destination element, and no other action is taken.

For vector convert floating to integer, where the source element is a reserved operand, the value written to the destination element is UNPREDICTABLE. In addition, the exception type and destination register number are recorded in the VAER. The vector operation is then allowed to complete.

For vector convert floating to floating instructions, if floating underflow occurs when cntrl<EXC> is clear, zero is written to the destination element, and no other action is taken. The vector operation is then allowed to complete.

For vector convert floating to floating instructions, if floating underflow occurs with cntrl<EXC> set or if a floating overflow or reserved operand occurs, an encoded reserved operand is written to the destination element, and the exception condition type and destination register number are recorded in the VAER. The vector operation is then allowed to complete.

## VDIV

Vector Floating Divide

### Format

vector/vector:

$$\left\{ \begin{array}{l} \text{VVDIVF} \\ \text{VVDIVD} \\ \text{VVDIVG} \end{array} \right\} [\text{U}[0|1]] \quad \text{Va, Vb, Vc}$$

scalar/vector:

$$\left\{ \begin{array}{l} \text{VSDIVF} \\ \text{VSDIVD} \\ \text{VSDIVG} \end{array} \right\} [\text{U}[0|1]] \quad \text{scalar, Vb, Vc}$$

### Architecture

#### Format

vector/vector:

*opcode cntrl.rw*

scalar/vector (F\_floating):

*opcode cntrl.rw, divd.rl*

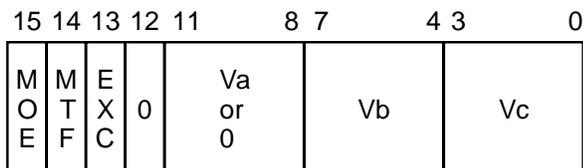
scalar/vector (D\_ and G\_floating):

*opcode cntrl.rw, divd.rq*

#### Opcodes

|      |        |                                 |
|------|--------|---------------------------------|
| ACFD | VVDIVF | Vector Vector Divide F_floating |
| ADFD | VSDIVF | Vector Scalar Divide F_floating |
| AEFD | VVDIVD | Vector Vector Divide D_floating |
| AFFD | VSDIVD | Vector Scalar Divide D_floating |
| AAFD | VVDIVG | Vector Vector Divide G_floating |
| ABFD | VSDIVG | Vector Scalar Divide G_floating |

#### vector\_control\_word



ZK-1461A-GE

#### Exceptions

- floating divide by zero
- floating overflow
- floating reserved operand

floating underflow

## Description

The scalar dividend or vector register *Va* is divided, elementwise, by the divisor in vector register *Vb* and the quotient is written to vector register *Vc*. The length of the vector is specified by the Vector Length Register (VLR).

In *VxDIVF*, only bits <31:0> of each vector element participate in the operation; bits <63:32> of the destination vector elements are UNPREDICTABLE.

If a floating underflow occurs when *cntrl*<EXC> is set or if a floating overflow, divide by zero, or reserved operand occurs, an encoded reserved operand is stored as the result and the exception condition type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER). The vector operation is then allowed to complete. If *cntrl*<EXC> is clear, zero is written to the destination element when an exponent underflow occurs and no other action is taken.

# VAX Instruction Set

## VMUL

### VMUL

Vector Floating Multiply

#### Format

vector \* vector:

VVMULF  
 VVMULD [U[0 | 1]] Va, Vb, Vc  
 VVMULG

scalar \* vector:

{ VSMULF  
 VSMULD } [U[0 | 1]] scalar, Vb, Vc  
 VSMULG }

#### Architecture

##### Format

vector \* vector:

*opcode cntrl.rw*

scalar \* vector (F\_floating):

*opcode cntrl.rw, mulr.rl*

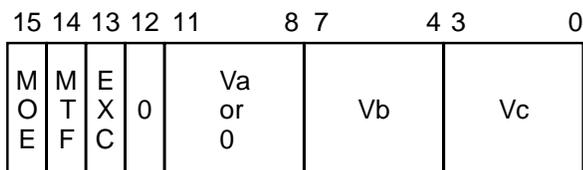
scalar \* vector (D\_ and G\_floating):

*opcode cntrl.rw, mulr.rq*

##### Opcodes

|      |        |                                   |
|------|--------|-----------------------------------|
| A4FD | VVMULF | Vector Vector Multiply F_floating |
| A5FD | VSMULF | Vector Scalar Multiply F_floating |
| A6FD | VVMULD | Vector Vector Multiply F_floating |
| A7FD | VSMULD | Vector Scalar Multiply D_floating |
| A2FD | VVMULG | Vector Vector Multiply G_floating |
| A3FD | VSMULG | Vector Scalar Multiply G_floating |

##### vector\_control\_word



ZK-1461A-GE

##### Exceptions

floating overflow  
 floating reserved operand  
 floating underflow

## Description

The multiplicand in vector register Vb is multiplied, elementwise, by the scalar multiplier or vector operand Va and the product is written to vector register Vc. The length of the vector is specified by the Vector Length Register (VLR).

In VxMULF, only bits <31:0> of each vector element participate in the operation. Bits <63:32> of the destination vector elements are UNPREDICTABLE.

If a floating underflow occurs when cntrl<EXC> is set or if a floating overflow or reserved operand occurs, an encoded reserved operand is stored as the result and the exception condition type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER). The vector operation is then allowed to complete. If cntrl<EXC> is clear, zero is written to the destination element when an exponent underflow occurs and no other action is taken.

## VSUB

Vector Floating Subtract

### Format

vector–vector:

$$\left\{ \begin{array}{l} \text{VSUBF} \\ \text{VVSUBD} \\ \text{VVSUBG} \end{array} \right\} \text{ [/U[0 | 1]] } \quad \text{Va, Vb, Vc}$$

scalar–vector:

$$\left\{ \begin{array}{l} \text{VSSUBF} \\ \text{VSSUBD} \\ \text{VSSUBG} \end{array} \right\} \text{ [/U[0 | 1]] } \quad \text{scalar, Vb, Vc}$$

### Architecture

#### Format

vector–vector:

*opcode cntrl.rw*

scalar–vector (F\_floating):

*opcode cntrl.rw, min.rl*

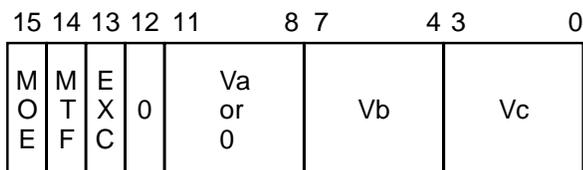
scalar–vector (D\_ and G\_floating):

*opcode cntrl.rw, min.rq*

#### Opcodes

|      |        |                                   |
|------|--------|-----------------------------------|
| 8CFD | VVSUBF | Vector Vector Subtract F_floating |
| 8DFD | VSSUBF | Vector Scalar Subtract F_floating |
| 8EFD | VVSUBD | Vector Vector Subtract D_floating |
| 8FFD | VSSUBD | Vector Scalar Subtract D_floating |
| 8AFD | VVSUBG | Vector Vector Subtract G_floating |
| 8BFD | VSSUBG | Vector Scalar Subtract G_floating |

#### vector\_control\_word



ZK-1461A-GE

#### Exceptions

- floating overflow
- floating reserved operand
- floating underflow

## Description

Vector register Vb is subtracted, elementwise, from the scalar minuend or vector register Va and the difference is written to vector register Vc. The length of the vector is specified by the Vector Length Register (VLR).

In VxSUBF, only bits <31:0> of each vector element participate in the operation; bits <63:32> of the destination vector elements are UNPREDICTABLE.

If a floating underflow occurs when cntrl<EXC> is set or if a floating overflow or reserved operand occurs, an encoded reserved operand is stored as the result and the exception condition type and destination register number are recorded in the Vector Arithmetic Exception Register (VAER). The vector operation is then allowed to complete. If cntrl<EXC> is clear, zero is written to the destination element when an exponent underflow occurs and no other action is taken.

---

## 10.14 Vector Edit Instructions

This section describes VAX vector architecture edit instructions.

# VAX Instruction Set

## VMERGE

### VMERGE

Vector Merge

#### Format

vector vector merge:

VVMERGE [0|1] Va, Vb, Vc

vector scalar merge:

$$\left\{ \begin{array}{l} \text{VSMERGE} \\ \text{VSMERGEF} \\ \text{VSMERGED} \\ \text{VSMERGE G} \end{array} \right\} \{ [0|1] \text{ src, Vb, Vc } \}$$

#### Architecture

##### Format

*vector-vector:* opcode cntrl.rw

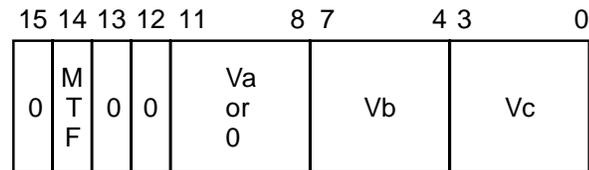
*vector-scalar:* opcode cntrl.rw,src.rq

##### Opcodes

EEFD VVMERGE Vector Vector Merge

EFFD VSMERGE Vector Scalar Merge

##### vector\_control\_word



ZK-1466A-GE

##### Exceptions

None.

#### Description

The scalar src or vector operand Va is merged, elementwise, with vector register Vb and the resulting vector is written to vector register Vc. The length of the vector operation is specified by the Vector Length Register (VLR).

For each vector element, i, if the corresponding Vector Mask Register bit (VMR<i>) matches cntrl<MTF>, src or Va[i] is written to the destination vector element Vc[i]. If VMR<i> does not match cntrl<MTF>, Vb[i] is written to the destination vector element.

## IOTA

Generate Compressed Iota Vector

### Format

IOTA [0|1] stride, Vc

### Architecture

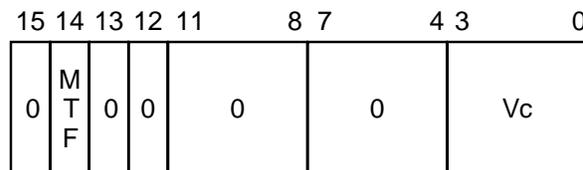
#### Format

*opcode* *cntrl.rw, stride.rl*

#### Opcodes

EDFD IOTA Generate Compressed Iota Vector

#### vector\_control\_word



ZK-1467A-GE

#### Exceptions

None.

### Description

IOTA constructs a vector of offsets for use by the vector gather/scatter instructions VGATH and VSCAT.

IOTA first generates an iota vector of length VLR using the stride operand. An iota vector is a vector whose first element is zero and whose subsequent elements are spaced by the stride increment. The stride can be positive, negative, or zero. For example:

$0*stride, 1*stride, 2*stride, 3*stride, \dots, \{VLR-1\}*stride$

The iota vector is then compressed using the contents of the Vector Mask Register (VMR). Elements of the iota vector for which the corresponding Vector Mask Register bit matches *cntrl*<MTF> are written in contiguous elements of the destination vector register Vc. Only bits <31:0> of each iota and destination vector element participate in the operation. Bits <63:32> of the destination vector elements are UNPREDICTABLE.

The number of elements written to Vc is returned in the Vector Count Register (VCR). The values of elements in the destination vector register between the new value of VCR and the vector length are UNPREDICTABLE.

---

**Note**

---

If a large value is specified for the stride.rl operand, there is a chance for integer overflow during calculation of the "tmp <- tmp + stride" step. In this case, the overflow is ignored. For example:

```
tmp <- tmp + stride
```

```
Value of tmp before above step: FFFFFFF0
```

```
Value of Stride:                FFFFFFF0
```

```
Value of tmp + stride:          1 FFFFE00
```

```
Since the overflow is ignored, the new value of tmp  
is FFFFE00.
```

---

---

## 10.15 Miscellaneous Instructions

This section describes VAX vector architecture miscellaneous instructions.

## MFVP

Move from Vector Processor

### Format

|         |   |     |
|---------|---|-----|
| MFVCR   | } | dst |
| MFVLR   |   |     |
| MFVMRLO |   |     |
| MFVMRHI |   |     |
| SYNCH   |   |     |
| MSYNCH  |   |     |

### Architecture

#### Format

*opcode regnum.rw, dst.wl*

#### Opcodes

31FD MFVP Move from Vector Processor

#### vector\_control\_word

None.

#### Exceptions

None.

MFVP instructions that specify reserved values of the regnum operand produce UNPREDICTABLE results.

### Description

This instruction can be used to read the Vector Count, Length, and Mask Registers, and to synchronize a scalar processor with its associated vector processor.

When the scalar processor issues an MFVP instruction to the vector processor, the scalar processor waits for the MFVP result to be written before processing other instructions.

MFVP from VCR or VLR does not read that register until all previous write operations to the register are completed. MFVP from VMR<31:0> or VMR<63:32> does not read that longword of VMR until all previous write operations to the same longword of VMR are completed; however, this is not true for previous write operations to the other longword.

SYNC allows software to ensure that the unreported exceptions of all previously issued vector instructions (including vector memory instructions in asynchronous memory management mode) are detected and reported to the scalar processor before the scalar processor proceeds with further instructions. For more details about SYNC and its exception reporting nature refer to Section 10.7.1, Scalar/Vector Instruction Synchronization.

## VAX Instruction Set

### MFVP

MSYNC allows software to ensure that all previously issued memory instructions of the scalar/vector processor pair are complete before the scalar processor proceeds with further instructions. For more details about MSYNC and its exception reporting nature, refer to Section 10.7.2, Memory Instruction Synchronization.

The value of the vector control register (VCR, VLR, VMR<31:0>, VMR<63:32>) delivered by an MFVP depends upon the value of certain vector register elements and vector control register bits. Unreported exceptions that occur in the production of these elements and control register bits are reported by the vector processor prior to the completion of the MFVP from the vector control register.

In addition, there are vector register elements and vector control register bits that the value of a vector control register delivered by an MFVP does not depend upon. It is UNPREDICTABLE whether unreported exceptions that occur in the production of these elements and control register bits are reported by the vector processor prior to the completion of the MFVP from the vector control register. Software must not rely upon the reporting of these exceptions prior to the completion of the MFVP for the correctness of program results.

Section 10.5.3.3, Dependencies Among Vector Results, gives the necessary rules to determine what vector control register elements and vector control register bits the value of a vector control register delivered by an MFVP depends upon. Examples of MFVP exception reporting using these rules are found in Section 10.6.5.

When a vector arithmetic exception or memory management exception (in asynchronous memory management mode) is reported prior to the completion of an MFVP, the following occur:

- The operation of the MFVP does not complete.
- No longword result is written to the scalar destination of the MFVP by the scalar processor.
- The MFVP itself (rather than the next vector instruction) takes either a vector processor disabled fault or a memory management fault.

After the appropriate fault has been serviced, the MFVP may be returned to through an REI. If both exception conditions are encountered by an MFVP, then the MFVP itself takes a vector processor disabled fault. In this case, after the vector processor disabled fault has been serviced, returning to the MFVP instruction will cause the asynchronous memory management exception to be reported.

---

## MTVP

Move to Vector Processor

### Format

$$\left\{ \begin{array}{l} \text{MTVCR} \\ \text{MTVLR} \\ \text{MTVMRLO} \\ \text{MTVMRHI} \end{array} \right\} \text{ src}$$

### Architecture

#### Format

*opcode regnum.rw, src.rl*

#### Opcodes

A9FD      MTVP      Move to Vector Processor

#### vector\_control\_word

None.

#### Exceptions

None.

Move to Vector Processor instructions that specify reserved values of the regnum operand produce UNPREDICTABLE results.

### Description

This instruction can be used to write the Vector Count, Length, and Mask Registers.

The new value of VCR, VLR, or VMR does not affect any prior instructions. The new value remains in effect for all subsequent vector instructions executed until a new value is loaded.

## VSYNC

Synchronize Vector Memory Access

### Format

VSYNCH

### Architecture

#### Format

*opcode* *regnum.rw*

#### Opcodes

A8FD      VSYNC      Synchronize Vector Memory Access

#### vector\_control\_word

None.

#### Exceptions

None.

Synchronize Vector Memory Access instructions that specify reserved values of the regnum operand produce UNPREDICTABLE results.

### Description

The VSYNC instruction can be used to synchronize memory access within the vector processor. The instruction allows software to order the conflicting memory accesses of vector-memory instructions issued after VSYNC with those of vector-memory instructions issued before VSYNC. Specifically, VSYNC forces the access of a memory location by any subsequent vector-memory instruction to wait for (depend upon) the completion of all prior conflicting accesses of that location by previous vector-memory instructions. See Section 10.7.1 for more details.

See Section 10.7.5, Required Use of Memory Synchronization Instructions, for the conditions when VSYNC is not required before a vector store instruction.

# A

## ASCII Character Set

| Dec              | Hex              | ASCII | Dec              | Hex              | ASCII | Dec              | Hex              | ASCII | Dec               | Hex              | ASCII |
|------------------|------------------|-------|------------------|------------------|-------|------------------|------------------|-------|-------------------|------------------|-------|
| 00 <sub>10</sub> | 00 <sub>16</sub> | NUL   | 32 <sub>10</sub> | 20 <sub>16</sub> | SP    | 64 <sub>10</sub> | 40 <sub>16</sub> | @     | 96 <sub>10</sub>  | 60 <sub>16</sub> | '     |
| 01 <sub>10</sub> | 01 <sub>16</sub> | SOH   | 33 <sub>10</sub> | 21 <sub>16</sub> | !     | 65 <sub>10</sub> | 41 <sub>16</sub> | A     | 97 <sub>10</sub>  | 61 <sub>16</sub> | a     |
| 02 <sub>10</sub> | 02 <sub>16</sub> | STX   | 34 <sub>10</sub> | 22 <sub>16</sub> | "     | 66 <sub>10</sub> | 42 <sub>16</sub> | B     | 98 <sub>10</sub>  | 62 <sub>16</sub> | b     |
| 03 <sub>10</sub> | 03 <sub>16</sub> | ETX   | 35 <sub>10</sub> | 23 <sub>16</sub> | #     | 67 <sub>10</sub> | 43 <sub>16</sub> | C     | 99 <sub>10</sub>  | 63 <sub>16</sub> | c     |
| 04 <sub>10</sub> | 04 <sub>16</sub> | EOT   | 36 <sub>10</sub> | 24 <sub>16</sub> | \$    | 68 <sub>10</sub> | 44 <sub>16</sub> | D     | 100 <sub>10</sub> | 64 <sub>16</sub> | d     |
| 05 <sub>10</sub> | 05 <sub>16</sub> | ENQ   | 37 <sub>10</sub> | 25 <sub>16</sub> | %     | 69 <sub>10</sub> | 45 <sub>16</sub> | E     | 101 <sub>10</sub> | 65 <sub>16</sub> | e     |
| 06 <sub>10</sub> | 06 <sub>16</sub> | ACK   | 38 <sub>10</sub> | 26 <sub>16</sub> | &     | 70 <sub>10</sub> | 46 <sub>16</sub> | F     | 102 <sub>10</sub> | 66 <sub>16</sub> | f     |
| 07 <sub>10</sub> | 07 <sub>16</sub> | BEL   | 39 <sub>10</sub> | 27 <sub>16</sub> | '     | 71 <sub>10</sub> | 47 <sub>16</sub> | G     | 103 <sub>10</sub> | 67 <sub>16</sub> | g     |
| 08 <sub>10</sub> | 08 <sub>16</sub> | BS    | 40 <sub>10</sub> | 28 <sub>16</sub> | (     | 72 <sub>10</sub> | 48 <sub>16</sub> | H     | 104 <sub>10</sub> | 68 <sub>16</sub> | h     |
| 09 <sub>10</sub> | 09 <sub>16</sub> | HT    | 41 <sub>10</sub> | 29 <sub>16</sub> | )     | 73 <sub>10</sub> | 49 <sub>16</sub> | I     | 105 <sub>10</sub> | 69 <sub>16</sub> | i     |
| 10 <sub>10</sub> | 0A <sub>16</sub> | LF    | 42 <sub>10</sub> | 2A <sub>16</sub> | *     | 74 <sub>10</sub> | 4A <sub>16</sub> | J     | 106 <sub>10</sub> | 6A <sub>16</sub> | j     |
| 11 <sub>10</sub> | 0B <sub>16</sub> | VT    | 43 <sub>10</sub> | 2B <sub>16</sub> | +     | 75 <sub>10</sub> | 4B <sub>16</sub> | K     | 107 <sub>10</sub> | 6B <sub>16</sub> | k     |
| 12 <sub>10</sub> | 0C <sub>16</sub> | FF    | 44 <sub>10</sub> | 2C <sub>16</sub> | ,     | 76 <sub>10</sub> | 4C <sub>16</sub> | l     | 108 <sub>10</sub> | 6C <sub>16</sub> | l     |
| 13 <sub>10</sub> | 0D <sub>16</sub> | CR    | 45 <sub>10</sub> | 2D <sub>16</sub> | -     | 77 <sub>10</sub> | 4D <sub>16</sub> | M     | 109 <sub>10</sub> | 6D <sub>16</sub> | m     |
| 14 <sub>10</sub> | 0E <sub>16</sub> | SO    | 46 <sub>10</sub> | 2E <sub>16</sub> | .     | 78 <sub>10</sub> | 4E <sub>16</sub> | N     | 110 <sub>10</sub> | 6E <sub>16</sub> | n     |
| 15 <sub>10</sub> | 0F <sub>16</sub> | SI    | 47 <sub>10</sub> | 2F <sub>16</sub> | /     | 79 <sub>10</sub> | 4F <sub>16</sub> | O     | 111 <sub>10</sub> | 6F <sub>16</sub> | o     |
| 16 <sub>10</sub> | 10 <sub>16</sub> | DLE   | 48 <sub>10</sub> | 30 <sub>16</sub> | 0     | 80 <sub>10</sub> | 50 <sub>16</sub> | P     | 112 <sub>10</sub> | 70 <sub>16</sub> | p     |
| 17 <sub>10</sub> | 11 <sub>16</sub> | DC1   | 49 <sub>10</sub> | 31 <sub>16</sub> | 1     | 81 <sub>10</sub> | 51 <sub>16</sub> | Q     | 113 <sub>10</sub> | 71 <sub>16</sub> | q     |
| 18 <sub>10</sub> | 12 <sub>16</sub> | DC2   | 50 <sub>10</sub> | 32 <sub>16</sub> | 2     | 82 <sub>10</sub> | 52 <sub>16</sub> | R     | 114 <sub>10</sub> | 72 <sub>16</sub> | r     |
| 19 <sub>10</sub> | 13 <sub>16</sub> | DC3   | 51 <sub>10</sub> | 33 <sub>16</sub> | 3     | 83 <sub>10</sub> | 53 <sub>16</sub> | S     | 115 <sub>10</sub> | 73 <sub>16</sub> | s     |
| 20 <sub>10</sub> | 14 <sub>16</sub> | DC4   | 52 <sub>10</sub> | 34 <sub>16</sub> | 4     | 84 <sub>10</sub> | 54 <sub>16</sub> | T     | 116 <sub>10</sub> | 74 <sub>16</sub> | t     |
| 21 <sub>10</sub> | 15 <sub>16</sub> | NAK   | 53 <sub>10</sub> | 35 <sub>16</sub> | 5     | 85 <sub>10</sub> | 55 <sub>16</sub> | U     | 117 <sub>10</sub> | 75 <sub>16</sub> | u     |
| 22 <sub>10</sub> | 16 <sub>16</sub> | SYN   | 54 <sub>10</sub> | 36 <sub>16</sub> | 6     | 86 <sub>10</sub> | 56 <sub>16</sub> | V     | 118 <sub>10</sub> | 76 <sub>16</sub> | v     |
| 23 <sub>10</sub> | 17 <sub>16</sub> | ETB   | 55 <sub>10</sub> | 37 <sub>16</sub> | 7     | 87 <sub>10</sub> | 57 <sub>16</sub> | W     | 119 <sub>10</sub> | 77 <sub>16</sub> | w     |
| 24 <sub>10</sub> | 18 <sub>16</sub> | CAN   | 56 <sub>10</sub> | 38 <sub>16</sub> | 8     | 88 <sub>10</sub> | 58 <sub>16</sub> | X     | 120 <sub>10</sub> | 78 <sub>16</sub> | x     |
| 25 <sub>10</sub> | 19 <sub>16</sub> | EM    | 57 <sub>10</sub> | 39 <sub>16</sub> | 9     | 89 <sub>10</sub> | 59 <sub>16</sub> | Y     | 121 <sub>10</sub> | 79 <sub>16</sub> | y     |
| 26 <sub>10</sub> | 1A <sub>16</sub> | SUB   | 58 <sub>10</sub> | 3A <sub>16</sub> | :     | 90 <sub>10</sub> | 5A <sub>16</sub> | Z     | 122 <sub>10</sub> | 7A <sub>16</sub> | z     |
| 27 <sub>10</sub> | 1B <sub>16</sub> | ESC   | 59 <sub>10</sub> | 3B <sub>16</sub> | ;     | 91 <sub>10</sub> | 5B <sub>16</sub> | [     | 123 <sub>10</sub> | 7B <sub>16</sub> | {     |
| 28 <sub>10</sub> | 1C <sub>16</sub> | FS    | 60 <sub>10</sub> | 3C <sub>16</sub> | <     | 92 <sub>10</sub> | 5C <sub>16</sub> | \     | 124 <sub>10</sub> | 7C <sub>16</sub> |       |
| 29 <sub>10</sub> | 1D <sub>16</sub> | GS    | 61 <sub>10</sub> | 3D <sub>16</sub> | =     | 93 <sub>10</sub> | 5D <sub>16</sub> | ]     | 125 <sub>10</sub> | 7D <sub>16</sub> | }     |
| 30 <sub>10</sub> | 1E <sub>16</sub> | RS    | 62 <sub>10</sub> | 3E <sub>16</sub> | >     | 94 <sub>10</sub> | 5E <sub>16</sub> | ^     | 126 <sub>10</sub> | 7E <sub>16</sub> | ~     |
| 31 <sub>10</sub> | 1F <sub>16</sub> | US    | 63 <sub>10</sub> | 3F <sub>16</sub> | ?     | 95 <sub>10</sub> | 5F <sub>16</sub> | _     | 127 <sub>10</sub> | 7F <sub>16</sub> | DEL   |



# B

## Hexadecimal/Decimal Conversion

The following table lists the decimal value for each possible hexadecimal value in each byte of a longword. The following sections contain instructions to use the table to convert hexadecimal numbers to decimal and decimal numbers to hexadecimal.

Hexadecimal to Decimal Conversion Table

| 8   |               | 7   |             | 6   |            | 5   |         | 4   |        | 3   |       | 2   |     | 1   |     |
|-----|---------------|-----|-------------|-----|------------|-----|---------|-----|--------|-----|-------|-----|-----|-----|-----|
| HEX | DEC           | HEX | DEC         | HEX | DEC        | HEX | DEC     | HEX | DEC    | HEX | DEC   | HEX | DEC | HEX | DEC |
| 0   | 0             | 0   | 0           | 0   | 0          | 0   | 0       | 0   | 0      | 0   | 0     | 0   | 0   | 0   | 0   |
| 1   | 268,435,456   | 1   | 16,777,216  | 1   | 1,048,576  | 1   | 65,536  | 1   | 4,096  | 1   | 256   | 1   | 16  | 1   | 1   |
| 2   | 536,870,912   | 2   | 33,554,432  | 2   | 2,097,152  | 2   | 131,072 | 2   | 8,192  | 2   | 512   | 2   | 32  | 2   | 2   |
| 3   | 805,306,368   | 3   | 50,331,648  | 3   | 3,145,728  | 3   | 196,608 | 3   | 12,288 | 3   | 768   | 3   | 48  | 3   | 3   |
| 4   | 1,073,741,824 | 4   | 67,108,864  | 4   | 4,194,304  | 4   | 262,144 | 4   | 16,384 | 4   | 1,024 | 4   | 64  | 4   | 4   |
| 5   | 1,342,177,280 | 5   | 83,886,080  | 5   | 5,242,880  | 5   | 327,680 | 5   | 20,480 | 5   | 1,280 | 5   | 80  | 5   | 5   |
| 6   | 1,610,612,736 | 6   | 100,663,296 | 6   | 6,291,456  | 6   | 393,216 | 6   | 24,576 | 6   | 1,536 | 6   | 96  | 6   | 6   |
| 7   | 1,879,048,192 | 7   | 117,440,512 | 7   | 7,340,032  | 7   | 458,752 | 7   | 28,672 | 7   | 1,792 | 7   | 112 | 7   | 7   |
| 8   | 2,147,483,648 | 8   | 134,217,728 | 8   | 8,388,608  | 8   | 524,288 | 8   | 32,768 | 8   | 2,048 | 8   | 128 | 8   | 8   |
| 9   | 2,415,919,104 | 9   | 150,994,944 | 9   | 9,437,184  | 9   | 589,824 | 9   | 36,864 | 9   | 2,304 | 9   | 144 | 9   | 9   |
| A   | 2,684,354,560 | A   | 167,772,160 | A   | 10,485,760 | A   | 655,360 | A   | 40,960 | A   | 2,560 | A   | 160 | A   | 10  |
| B   | 2,952,790,016 | B   | 184,549,376 | B   | 11,534,336 | B   | 720,896 | B   | 45,056 | B   | 2,816 | B   | 176 | B   | 11  |
| C   | 3,221,225,472 | C   | 201,326,592 | C   | 12,582,912 | C   | 786,432 | C   | 49,152 | C   | 3,072 | C   | 192 | C   | 12  |
| D   | 3,489,660,928 | D   | 218,103,808 | D   | 13,631,488 | D   | 851,968 | D   | 53,248 | D   | 3,328 | D   | 208 | D   | 13  |
| E   | 3,758,096,384 | E   | 234,881,024 | E   | 14,680,064 | E   | 917,504 | E   | 57,344 | E   | 3,584 | E   | 224 | E   | 14  |
| F   | 4,026,531,840 | F   | 251,658,240 | F   | 15,728,640 | F   | 983,040 | F   | 61,440 | F   | 3,840 | F   | 240 | F   | 15  |

ZK-2013-GE

### B.1 Hexadecimal to Decimal

For each integer position of the hexadecimal value, locate the corresponding column integer and record its decimal equivalent in the conversion table. Add the decimal equivalent to obtain the decimal value.

For example:

D0500AD0 (hex) = ? (dec)  
D0000000 = 3,489,660,928  
500000 = 5,242,880  
A00 = 2,560  
D0 = 208  
D0500AD0 = 3,494,906,576

## Hexadecimal/Decimal Conversion

### B.2 Decimal to Hexadecimal

#### B.2 Decimal to Hexadecimal

To determine the hexadecimal equivalent of a given decimal value, perform the following steps:

1. In the conversion table, locate the largest decimal value that does not exceed the decimal number to be converted.
2. Record the hexadecimal equivalent, followed by the number of zeros that corresponds to the integer column minus 1.
3. Subtract the table decimal value from the decimal number to be converted.
4. Repeat steps 1 to 3 until the subtraction balance equals zero. Add the hexadecimal equivalents to obtain the hexadecimal value.

For example:

$$\begin{array}{r}
 22,466 \text{ (dec)} = ? \text{ (hex)} \\
 20,480 = 5000 \quad 22,466 \\
 1,792 = 700 \quad -20,480 \\
 192 = C0 \\
 2 = 2 \quad 1,986 \\
 \quad - 1,792 \\
 22,466 = 57C2 \\
 \quad \quad 194 \\
 \quad - 192 \\
 \quad \quad 2 \\
 \quad - 2 \\
 \quad \quad 0
 \end{array}$$

#### B.3 Powers of 2 and 16

This section lists the decimal values of powers of 2 and 16. These values are useful in converting decimal numbers to hexadecimal.

| Powers of 2 |    | Powers of 16        |    |
|-------------|----|---------------------|----|
| 2**n        | n  | 16**n               | n  |
| 256         | 8  | 1                   | 0  |
| 512         | 9  | 16                  | 1  |
| 1024        | 10 | 256                 | 2  |
| 2048        | 11 | 4096                | 3  |
| 4096        | 12 | 65536               | 4  |
| 8192        | 13 | 1048576             | 5  |
| 16384       | 14 | 16777216            | 6  |
| 32768       | 15 | 268435456           | 7  |
| 65536       | 16 | 4294967296          | 8  |
| 131072      | 17 | 68719476736         | 9  |
| 262144      | 18 | 1099511627776       | 10 |
| 524288      | 19 | 17592186044416      | 11 |
| 1048576     | 20 | 281474976710656     | 12 |
| 2097152     | 21 | 4503599627370496    | 13 |
| 4194304     | 22 | 72057594037927936   | 14 |
| 8388608     | 23 | 1152921504606846976 | 15 |
| 16777216    | 24 |                     |    |

# VAX MACRO Assembler Directives and Language Summary

This appendix summarizes the general assembler and macro directives (in alphabetical order), special characters, unary operators, binary operators, and addressing modes.

## C.1 Assembler Directives

Table C-1 summarizes the VAX MACRO assembler directives.

**Table C-1 Assembler Directives**

| <b>Format</b>               | <b>Operation</b>  |
|-----------------------------|---|
| .ADDRESS address-list       | Stores successive longwords of address data                                       |
| .ALIGN keyword[,expression] | Aligns the location counter to the boundary specified by the keyword              |
| .ALIGN integer[,expression] | Aligns location counter to the boundary specified by $(2^{\text{integer}})$       |
| .ASCIC string               | Stores the ASCII string (enclosed in delimiters), preceded by a count byte        |
| .ASCID string               | Stores the ASCII string (enclosed in delimiters), preceded by a string descriptor |
| .ASCII string               | Stores the ASCII string (enclosed in delimiters)                                  |
| .ASCIZ string               | Stores the ASCII string (enclosed in delimiters) followed by a 0 byte             |
| .BLKA expression            | Reserves longwords of address data  |
| .BLKB expression            | Reserves bytes for data   |
| .BLKD expression            | Reserves quadwords for double-precision floating-point data                       |
| .BLKF expression            | Reserves longwords for single-precision floating-point data                       |
| .BLKG expression            | Reserves quadwords for floating-point data  |
| .BLKH expression            | Reserves octawords for extended-precision floating-point data                     |
| .BLKL expression            | Reserves longwords for data   |

(continued on next page)

# VAX MACRO Assembler Directives and Language Summary

## C.1 Assembler Directives

**Table C-1 (Cont.) Assembler Directives**

| <b>Format</b>                  | <b>Operation</b>   |
|--------------------------------|--|
| .BLKO expression               | Reserves octawords for data  |
| .BLKQ expression               | Reserves quadwords for data  |
| .BLKW expression               | Reserves words for data  |
| .BYTE expression-list          | Generates successive bytes of data; each byte contains the value of the specified expression |
| .CROSS                         | Enables cross-referencing of all symbols   |
| .CROSS symbol-list             | Cross-references specified symbols   |
| .DEBUG symbol-list             | Makes symbol names known to the debugger   |
| .DEFAULT DISPLACEMENT, keyword | Specifies the default displacement length for the relative addressing modes                  |
| .D_FLOATING literal-list       | Generates 8-byte double-precision floating-point data  |
| .DISABLE argument-list         | Disables functions specified in argument-list  |
| .DOUBLE literal-list           | Equivalent to .D_FLOATING  |
| .DSABL argument-list           | Equivalent to .DISABLE   |
| .ENABL argument-list           | Equivalent to .ENABLE  |
| .ENABLE argument-list          | Enables functions specified in argument-list   |
| .END [symbol]                  | Indicates logical end of source program; optional symbol specifies transfer address          |
| .ENDC                          | Indicates end of conditional assembly block  |
| .ENDM [macro-name]             | Indicates end of macro definition  |
| .ENDR                          | Indicates end of repeat block  |
| .ENTRY symbol [,expression]    | Procedure entry directive  |
| .ERROR [expression] ;comment   | Displays specified error message   |
| .EVEN                          | Ensures that the current location counter has an even value (adds 1 if it is odd)            |
| .EXTERNAL symbol-list          | Indicates specified symbols are externally defined   |
| .EXTRN symbol-list             | Equivalent to .EXTERNAL  |
| .F_FLOATING literal-list       | Generates 4-byte single-precision floating-point data  |
| .FLOAT literal-list            | Equivalent to .F_FLOATING  |
| .G_FLOATING literal-list       | Generates 8-byte G_floating-point data   |

(continued on next page)

# VAX MACRO Assembler Directives and Language Summary

## C.1 Assembler Directives

**Table C-1 (Cont.) Assembler Directives**

| Format   | Operation   |
|--|---|
| .GLOBAL symbol-list                                    | Indicates specified symbols are global symbols  |
| .GLOBL   | Equivalent to .GLOBAL   |
| .H_FLOATING literal-list                               | Generates 16-byte extended-precision H_floating-point data  |
| .IDENT string  | Provides means of labeling object module with additional data   |
| .IF condition [,] argument(s)                          | Begins a conditional assembly block of source code, which is included in the assembly only if the stated condition is met with respect to the arguments specified |
| .IFF   | Equivalent to .IF_FALSE   |
| .IF_FALSE  | Appears only within a conditional assembly block; begins block of code to be assembled if the original condition tests false                                      |
| .IFT   | Equivalent to .IF_TRUE  |
| .IFTF  | Equivalent to .IF_TRUE_FALSE  |
| .IF_TRUE   | Appears only within a conditional assembly block; begins block of code to be assembled if the original condition tests true                                       |
| .IF_TRUE_FALSE   | Appears only within a conditional assembly block; begins block of code to be assembled unconditionally  |
| .IIF condition argument(s), statement                  | Acts as a 1-line conditional assembly block where the condition is tested for the argument specified; the statement is assembled only if the condition tests true |
| .IRP symbol,<argument list>                            | Replaces a formal argument with successive actual arguments specified in an argument list   |
| .IRPC symbol,<BIT_STRING>                              | Replaces a formal argument with successive single characters specified in string  |
| .LIBRARY macro-library-name                            | Specifies a macro library   |
| .LINK "file-spec" [/qualifier[(module-name[...])],...] | Includes linker option records in object module   |
| .LIST [argument-list]                                  | Equivalent to .SHOW   |
| .LONG expression-list                                  | Generates successive longwords of data; each longword contains the value of the specified expression  |
| .MACRO macro-name [formal-argument-list]               | Begins a macro definition   |
| .MASK symbol [,expression]                             | Reserves a word for and copies a register save mask   |

(continued on next page)

# VAX MACRO Assembler Directives and Language Summary

## C.1 Assembler Directives

**Table C–1 (Cont.) Assembler Directives**

| <b>Format</b>                                | <b>Operation</b>  |
|--|---|
| .MCALL macro-name-list                       | Specifies the system or user-defined macros, or both, in libraries that are required to assemble the source program |
| .MDELETE macro-name-list                     | Deletes from memory the macro definitions of the macros in the list   |
| .MEXIT                                       | Exits from the expansion of a macro before the end of the macro is encountered                                      |
| .NARG symbol                                 | Determines the number of arguments in the current macro call  |
| .NCHR symbol,<BIT_STRING>                    | Determines the number of characters in a specified character string   |
| .NLIST [argument-list]                       | Equivalent to .NOSHOW   |
| .NOCROSS                                     | Disables cross-referencing of all symbols   |
| .NOCROSS symbol-list                         | Disables cross-referencing of specified symbols   |
| .NOSHOW                                      | Decrements listing level count  |
| .NOSHOW argument-list                        | Controls listing of macros and conditional assembly blocks  |
| .NTYPE symbol,operand                        | Can appear only within a macro definition; equates the symbol to the addressing mode of the specified operand       |
| .OCTA literal                                | Stores 16 bytes of data   |
| .OCTA symbol                                 | Stores 16 bytes of data   |
| .ODD   | Ensures that the current location counter has an odd value (adds 1 if it is even)                                   |
| .OPDEF opcode value, operand-descriptor-list | Defines an opcode and its operand list  |
| .PACKED decimal-string [,symbol]             | Generates packed decimal data, 2 digits per byte  |
| .PAGE  | Causes the assembly listing to skip to the top of the next page and to increment the page count                     |
| .PRINT [expression] ;comment                 | Displays the specified message  |
| .PSECT                                       | Begins or resumes the blank program section   |
| .PSECT section-name argument list            | Begins or resumes a user-defined program section  |
| .QUAD literal                                | Stores 8 bytes of data  |
| .QUAD symbol                                 | Stores 8 bytes of data  |
| .REF1 operand                                | Generates byte operand  |
| .REF2 operand                                | Generates word operand  |

(continued on next page)

# VAX MACRO Assembler Directives and Language Summary

## C.1 Assembler Directives

**Table C–1 (Cont.) Assembler Directives**

| Format                            | Operation  |
|-----------------------------------|--|
| .REF4 operand                     | Generates longword operand   |
| .REF8 operand                     | Generates quadword operand   |
| .REF16 operand                    | Generates octaword operand   |
| .REPEAT expression                | Begins a repeat block; the section of code up to the next .ENDR directive is repeated the number of times specified by the expression  |
| .REPT                             | Equivalent to .REPEAT  |
| .RESTORE                          | Equivalent to .RESTORE_PSECT   |
| .RESTORE_PSECT                    | Restores program section context from the program section context stack  |
| .SAVE [LOCAL_BLOCK]               | Equivalent to .SAVE_PSECT  |
| .SAVE_PSECT [LOCAL_BLOCK]         | Saves current program section context on the program section context stack   |
| .SBTTL comment-string             | Equivalent to .SUBTITLE  |
| .SHOW                             | Increments listing level count   |
| .SHOW argument-list               | Controls listing of macros and conditional assembly blocks   |
| .SIGNED_BYTE expression-list      | Stores successive bytes of signed data   |
| .SIGNED_WORD expression-list      | Stores successive words of signed data   |
| .SUBTITLE comment-string          | Causes the specified string to be printed as part of the assembly listing page header; the string component of each .SUBTITLE is collected into a table of contents at the beginning of the assembly listing |
| .TITLE module-name comment-string | Assigns the first 15 characters in the string as an object module name and causes the string to appear on each page of the assembly listing  |
| .TRANSFER symbol                  | Directs the linker to redefine the value of the global symbol for use in a shareable image   |
| .WARN [expression] ;comment       | Displays specified warning message   |
| .WEAK symbol-list                 | Indicates that each of the listed symbols has the weak attribute   |
| .WORD expression-list             | Generates successive words of data; each word contains the value of the corresponding specified expression   |

## C.2 Special Characters

Table C–2 summarizes the VAX MACRO special characters.

## VAX MACRO Assembler Directives and Language Summary

### C.2 Special Characters

**Table C-2 Special Characters Used in VAX MACRO Statements**

| Character | Character Name    | Functions   |
|-----------|-------------------|---|
| _         | Underscore        | Character in symbol names   |
| \$        | Dollar sign       | Character in symbol names   |
| .         | Period            | Character in symbol names, current location counter, and decimal point  |
| :         | Colon             | Label terminator  |
| =         | Equal sign        | Direct assignment operator and macro keyword argument terminator  |
|           | Tab               | Field terminator  |
|           | Space             | Field terminator  |
| #         | Number sign       | Immediate addressing mode indicator   |
| @         | At sign           | Deferred addressing mode indicator and arithmetic shift operator  |
| ,         | Comma             | Field, operand, and item separator  |
| ;         | Semicolon         | Comment field indicator   |
| +         | Plus sign         | Autoincrement addressing mode indicator, unary plus operator, and arithmetic addition operator                                  |
| -         | Minus sign        | Autodecrement addressing mode indicator, unary minus operator, arithmetic subtraction operator, and line continuation indicator |
| *         | Asterisk          | Arithmetic multiplication operator  |
| /         | Slash             | Arithmetic division operator  |
| &         | Ampersand         | Logical AND operator  |
| !         | Exclamation point | Logical inclusive OR operator   |
| \         | Backslash         | Logical exclusive OR and numeric conversion indicator in macro arguments  |
| ^         | Circumflex        | Unary operator indicator and macro argument delimiter   |
| [ ]       | Square brackets   | Index addressing mode and repeat count indicators   |
| ( )       | Parentheses       | Register deferred addressing mode indicators  |
| <>        | Angle brackets    | Argument or expression grouping delimiters  |
| ?         | Question mark     | Created label indicator in macro arguments  |
| '         | Apostrophe        | Macro argument concatenation indicator  |
| %         | Percent sign      | Macro string operators  |

### C.3 Operators

This section lists the VAX MACRO unary, binary, and macro string operators.

# VAX MACRO Assembler Directives and Language Summary

## C.3 Operators

### C.3.1 Unary Operators

Table C-3 summarizes the VAX MACRO unary operators.

**Table C-3 Summary of Unary Operators**

| Unary Operator | Operator Name  | Example      | Effect   |
|----------------|----------------|--------------|--|
| +              | Plus sign      | +A           | Results in the positive value of A (default)   |
| -              | Minus sign     | -A           | Results in the negative (two's complement) value of A  |
| ^B             | Binary         | ^B11000111   | Specifies that 11000111 is a binary number   |
| ^D             | Decimal        | ^D127        | Specifies that 127 is a decimal number   |
| ^O             | Octal          | ^O34         | Specifies that 34 is an octal number   |
| ^X             | Hexadecimal    | ^XFCF9       | Specifies that FCF9 is a hexadecimal number  |
| ^A             | ASCII          | ^A/ABC/      | Produces an ASCII string; the characters between the matching delimiters are converted to ASCII representation |
| ^M             | Register mask  | ^M<R3,R4,R5> | Specifies the registers R3, R4, and R5 in the register mask  |
| ^F             | Floating point | ^F3.0        | Specifies that 3.0 is a floating-point number  |
| ^C             | Complement     | ^C24         | Produces the one's complement value of 24 (decimal)  |

### C.3.2 Binary Operators

Table C-4 summarizes the VAX MACRO binary operators.

**Table C-4 Summary of Binary Operators**

| Binary Operator | Operator Name     | Example | Operation            |
|-----------------|-------------------|---------|----------------------|
| +               | Plus sign         | A+B     | Addition             |
| -               | Minus sign        | A-B     | Subtraction          |
| *               | Asterisk          | A*B     | Multiplication       |
| /               | Slash             | A/B     | Division             |
| @               | At sign           | A@B     | Arithmetic Shift     |
| &               | Ampersand         | A&B     | Logical AND          |
| !               | Exclamation point | A!B     | Logical inclusive OR |

(continued on next page)

# VAX MACRO Assembler Directives and Language Summary

## C.3 Operators

Table C-4 (Cont.) Summary of Binary Operators

| Binary Operator | Operator Name | Example | Operation            |
|-----------------|---------------|---------|----------------------|
| \               | Backslash     | A\B     | Logical exclusive OR |

### C.3.3 Macro String Operators

Table C-5 summarizes the macro string operators. These operators can be used only in macros.

Table C-5 Macro String Operators

| Format                            | Function  |
|-----------------------------------|---|
| %LENGTH(string)                   | Returns the length of the string  |
| %LOCATE(string1,string2[,symbol]) | Locates the substring string1 within string2 starting the search at the character position specified by symbol                |
| %EXTRACT(symbol1,symbol2,string)  | Extracts a substring from string that begins at character position specified by symbol1 and has a length specified by symbol2 |

# VAX MACRO Assembler Directives and Language Summary

## C.4 Addressing Modes

### C.4 Addressing Modes

Table C-6 summarizes the VAX MACRO addressing modes.

**Table C-6 Summary of Addressing Modes**

| Type             | Addressing Mode        | Format   | Hex Value                                      | Description  | Can Be Indexed?   |
|------------------|------------------------|--|--|--|---|
| General register | Register               | Rn   | 5  | Register contains the operand.   | No  |
|                  | Register deferred      | (Rn)   | 6  | Register contains the address of the operand.  | Yes   |
|                  | Autoincrement          | (Rn)+  | 8  | Register contains the address of the operand; the processor increments the register contents by the size of the operand data type.   | Yes   |
|                  | Autoincrement deferred | @(Rn)+   | 9  | Register contains the address of the operand address; the processor increments the register contents by 4.   | Yes   |
|                  | Autodecrement          | -(Rn)  | 7  | The processor decrements the register contents by the size of the operand data type; the register then contains the address of the operand.  | Yes   |
|                  | Displacement           | dis(Rn)<br>B^dis(Rn)<br>W^dis(Rn)<br>L^dis(Rn)     | A<br>C<br>E                                    | The sum of the contents of the register and the displacement is the address of the operand; B^, W^, and L^, respectively, indicate byte, word, and longword displacement.          | Yes   |
|                  | Displacement deferred  | @dis(Rn)<br>@B^dis(Rn)<br>@W^dis(Rn)<br>@L^dis(Rn) | B<br>D<br>F                                    | The sum of the contents of the register and the displacement is the address of the operand address; B^, W^, and L^, respectively, indicate, byte, word, and longword displacement. | Yes   |
| Program Counter  | Literal                | #literal<br>S^#literal                             | 0-3  | The literal specified is the operand; the literal is stored as a short literal.  | No  |
|                  |                        | Relative   | address<br>B^address<br>W^address<br>L^address | A<br>C<br>E  | The address specified is the address of the operand; the address is stored as a displacement from the PC; B^, W^, and L^, respectively, indicate byte, word, and longword displacement. |

**Key:**

- Rn**—Any general register R0 to R12. Note that the AP, FP, or SP register can be used in place of Rn.
- Rx**—Any general register R0 to R12. Note that the AP, FP, or SP register can be used in place of Rx. Rx cannot be the same as the Rn specified in the base-mode for certain base modes (see Section 5.3).
- dis**—An expression specifying a displacement.
- address**—An expression specifying an address.
- literal**—An expression, an integer constant, or a floating-point constant.

(continued on next page)

# VAX MACRO Assembler Directives and Language Summary

## C.4 Addressing Modes

Table C-6 (Cont.) Summary of Addressing Modes

| Type   | Addressing Mode   | Format   | Hex Value   | Description  | Can Be Indexed? |
|--------|-------------------|--|-------------|--|-----------------|
|        | Relative deferred | @address<br>@B^address<br>@W^address<br>@L^address | B<br>D<br>F | The address specified is the address of the operand address; the address specified is stored as a displacement from the PC; B^, W^, and L^ indicate byte, word, and longword displacement, respectively.   | Yes             |
|        | Absolute          | @#address  | 9           | The address specified is the address of the operand; the address specified is stored as an absolute virtual address, not as a displacement.  | Yes             |
|        | Immediate         | #literal<br>I^#literal                             | 8           | The literal specified is the operand; the literal is stored as a byte, word, longword, or quadword.  | No              |
|        | General           | G^address  | —           | The address specified is the address of the operand; if the address is defined as relocatable, the linker stores the address as a displacement from the PC; if the address is defined as an absolute virtual address, the linker stores the address as an absolute value.  | Yes             |
| Index  | Index             | base-mode[Rx]                                      | 4           | The base-mode specifies the base address, and the register specifies the index; the sum of the base address and the product of the contents of Rx and the size of the operand data type is the address of the operand; base mode can be any addressing mode except register, immediate, literal, index, or branch. | No              |
| Branch | Branch            | address  | —           | The address specified is the operand; this address is stored as a displacement from the PC; branch mode can only be used with the branch instructions.   | No              |

**Key:**

- Rn**—Any general register R0 to R12. Note that the AP, FP, or SP register can be used in place of Rn.
- Rx**—Any general register R0 to R12. Note that the AP, FP, or SP register can be used in place of Rx. Rx cannot be the same as the Rn specified in the base-mode for certain base modes (see Section 5.3).
- dis**—An expression specifying a displacement.
- address**—An expression specifying an address.
- literal**—An expression, an integer constant, or a floating-point constant.

# D

## Permanent Symbol Table Defined for Use with VAX MACRO

The permanent symbol table (PST) contains the symbols that VAX MACRO automatically recognizes. These symbols consist of both opcodes and assembler directives. Table D-1, Table D-2, and Table D-3 present the opcodes (instruction set) in alphabetical and numerical order. Section C.1 (in Appendix C) presents the assembler directives.

See Chapter 9 and Chapter 10 for detailed descriptions of the instruction set.

**Table D-1 Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                   |
|-----------|----------|-----------------------------------|
| 9D        | ACBB     | Add compare and branch byte       |
| 6F        | ACBD     | Add compare and branch D_floating |
| 4F        | ACBF     | Add compare and branch F_floating |
| 4FFD      | ACBG     | Add compare and branch G_floating |
| 6FFD      | ACBH     | Add compare and branch H_floating |
| F1        | ACBL     | Add compare and branch longword   |
| 3D        | ACBW     | Add compare and branch word       |
| 58        | ADAWI    | Add aligned word interlocked      |
| 80        | ADDB2    | Add byte 2 operand                |
| 81        | ADDB3    | Add byte 3 operand                |
| 60        | ADDD2    | Add D_floating 2 operand          |
| 61        | ADDD3    | Add D_floating 3 operand          |
| 40        | ADDF2    | Add F_floating 2 operand          |
| 41        | ADDF3    | Add F_floating 3 operand          |
| 40FD      | ADDG2    | Add G_floating 2 operand          |
| 41FD      | ADDG3    | Add G_floating 3 operand          |
| 60FD      | ADDH2    | Add H_floating 2 operand          |
| 61FD      | ADDH3    | Add H_floating 3 operand          |
| C0        | ADDL2    | Add longword 2 operand            |
| C1        | ADDL3    | Add longword 3 operand            |
| 20        | ADDP4    | Add packed 4 operand              |
| 21        | ADDP6    | Add packed 6 operand              |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                           |
|-----------|----------|---|
| A0        | ADDW2    | Add word 2 operand                        |
| A1        | ADDW3    | Add word 3 operand                        |
| D8        | ADWC     | Add with carry                            |
| F3        | AOBLEQ   | Add one and branch on less or equal       |
| F2        | AOBLSS   | Add one and branch on less                |
| 78        | ASHL     | Arithmetic shift longword                 |
| F8        | ASHP     | Arithmetic shift and round packed         |
| 79        | ASHQ     | Arithmetic shift quadword                 |
| E1        | BBC      | Branch on bit clear                       |
| E5        | BBCC     | Branch on bit clear and clear             |
| E7        | BBCCI    | Branch on bit clear and clear interlocked |
| E3        | BBCS     | Branch on bit clear and set               |
| E0        | BBS      | Branch on bit set                         |
| E4        | BBSC     | Branch on bit set and clear               |
| E2        | BBSS     | Branch on bit set and set                 |
| E6        | BBSSI    | Branch on bit set and set interlocked     |
| 1E        | BCC      | Branch on carry clear                     |
| 1F        | BCS      | Branch on carry set                       |
| 13        | BEQL     | Branch on equal                           |
| 13        | BEQLU    | Branch on equal unsigned                  |
| 18        | BGEQ     | Branch on greater or equal                |
| 1E        | BGEQU    | Branch on greater or equal unsigned       |
| 14        | BGTR     | Branch on greater                         |
| 1A        | BGTRU    | Branch on greater unsigned                |
| 8A        | BICB2    | Bit clear byte 2 operand                  |
| 8B        | BICB3    | Bit clear byte 3 operand                  |
| CA        | BICL2    | Bit clear longword 2 operand              |
| CB        | BICL3    | Bit clear longword 3 operand              |
| B9        | BICPSW   | Bit clear program status word             |
| AA        | BICW2    | Bit clear word 2 operand                  |
| AB        | BICW3    | Bit clear word 3 operand                  |
| 88        | BISB2    | Bit set byte 2 operand                    |
| 89        | BISB3    | Bit set byte 3 operand                    |
| C8        | BISL2    | Bit set longword 2 operand                |
| C9        | BISL3    | Bit set longword 3 operand                |
| B8        | BISPSW   | Bit set program status word               |
| A8        | BISW2    | Bit set word 2 operand                    |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                             |
|-----------|----------|---|
| A9        | BISW3    | Bit set word 3 operand                      |
| 93        | BITB     | Bit test byte                               |
| D3        | BITL     | Bit test longword                           |
| B3        | BITW     | Bit test word                               |
| E9        | BLBC     | Branch on low bit clear                     |
| E8        | BLBS     | Branch on low bit set                       |
| 15        | BLEQ     | Branch on less or equal                     |
| 1B        | BLEQU    | Branch on less or equal unsigned            |
| 19        | BLSS     | Branch on less                              |
| 1F        | BLSSU    | Branch on less unsigned                     |
| 12        | BNEQ     | Branch on not equal                         |
| 12        | BNEQU    | Branch on not equal unsigned                |
| 03        | BPT      | Break point trap                            |
| 11        | BRB      | Branch with byte displacement               |
| 31        | BRW      | Branch with word displacement               |
| 10        | BSBB     | Branch to subroutine with byte displacement |
| 30        | BSBW     | Branch to subroutine with word displacement |
| 1C        | BVC      | Branch on overflow clear                    |
| 1D        | BVS      | Branch on overflow set                      |
| FA        | CALLG    | Call with general argument list             |
| FB        | CALLS    | Call with stack                             |
| 8F        | CASEB    | Case byte                                   |
| CF        | CASEL    | Case longword                               |
| AF        | CASEW    | Case word                                   |
| BD        | CHME     | Change mode to executive                    |
| BC        | CHMK     | Change mode to kernel                       |
| BE        | CHMS     | Change mode to supervisor                   |
| BF        | CHMU     | Change mode to user                         |
| 94        | CLRB     | Clear byte                                  |
| 7C        | CLRD     | Clear D_floating                            |
| DF        | CLRF     | Clear F_floating                            |
| 7C        | CLRG     | Clear G_floating                            |
| 7CFD      | CLRH     | Clear H_floating                            |
| D4        | CLRL     | Clear longword                              |
| 7CFD      | CLRO     | Clear octaword                              |
| 7C        | CLRQ     | Clear quadword                              |
| B4        | CLRW     | Clear word                                  |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                   |
|-----------|----------|-----------------------------------|
| 91        | CMPB     | Compare byte                      |
| 29        | CMPC3    | Compare character 3 operand       |
| 2D        | CMPC5    | Compare character 5 operand       |
| 71        | CMPD     | Compare D_floating                |
| 51        | CMPF     | Compare F_floating                |
| 51FD      | CMPG     | Compare G_floating                |
| 71FD      | CMPH     | Compare H_floating                |
| D1        | CMPL     | Compare longword                  |
| 35        | CMPP3    | Compare packed 3 operand          |
| 37        | CMPP4    | Compare packed 4 operand          |
| EC        | CMPV     | Compare field                     |
| B1        | CMPW     | Compare word                      |
| ED        | CMPZV    | Compare zero-extended field       |
| 0B        | CRC      | Calculate cyclic redundancy check |
| 6C        | CVTBD    | Convert byte to D_floating        |
| 4C        | CVTBF    | Convert byte to F_floating        |
| 4CFD      | CVTBG    | Convert byte to G_floating        |
| 6CFD      | CVTBH    | Convert byte to H_floating        |
| 98        | CVTBL    | Convert byte to longword          |
| 99        | CVTBW    | Convert byte to word              |
| 68        | CVTDB    | Convert D_floating to byte        |
| 76        | CVTDF    | Convert D_floating to F_floating  |
| 32FD      | CVTDH    | Convert D_floating to H_floating  |
| 6A        | CVTDL    | Convert D_floating to longword    |
| 69        | CVTDW    | Convert D_floating to word        |
| 48        | CVTFB    | Convert F_floating to byte        |
| 56        | CVTFD    | Convert F_floating to D_floating  |
| 99FD      | CVTFG    | Convert F_floating to G_floating  |
| 98FD      | CVTFH    | Convert F_floating to H_floating  |
| 4A        | CVTFL    | Convert F_floating to longword    |
| 49        | CVTFW    | Convert F_floating to word        |
| 48FD      | CVTGB    | Convert G_floating to byte        |
| 33FD      | CVTGF    | Convert G_floating to F_floating  |
| 56FD      | CVTGH    | Convert G_floating to H_floating  |
| 4AFD      | CVTGL    | Convert G_floating to longword    |
| 49FD      | CVTGW    | Convert G_floating to word        |
| 68FD      | CVTHB    | Convert H_floating to byte        |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                        |
|-----------|----------|--|
| F7FD      | CVTHD    | Convert H_floating to D_floating       |
| F6FD      | CVTHF    | Convert H_floating to F_floating       |
| 76FD      | CVTHG    | Convert H_floating to G_floating       |
| 6AFD      | CVTHL    | Convert H_floating to longword         |
| 69FD      | CVTHW    | Convert H_floating to word             |
| F6        | CVTLB    | Convert longword to byte               |
| 6E        | CVTLD    | Convert longword to D_floating         |
| 4E        | CVTLF    | Convert longword to F_floating         |
| 4EFD      | CVTLG    | Convert longword to G_floating         |
| 6EFD      | CVTLH    | Convert longword to H_floating         |
| F9        | CVTLP    | Convert longword to packed             |
| F7        | CVTLW    | Convert longword to word               |
| 36        | CVTPL    | Convert packed to longword             |
| 08        | CVTPS    | Convert packed to leading separate     |
| 24        | CVTPT    | Convert packed to trailing             |
| 6B        | CVTRDL   | Convert rounded D_floating to longword |
| 4B        | CVTRFL   | Convert rounded F_floating to longword |
| 4BFD      | CVTRGL   | Convert rounded G_floating to longword |
| 6BFD      | CVTRHL   | Convert rounded H_floating to longword |
| 09        | CVTSP    | Convert leading separate to packed     |
| 26        | CVTTP    | Convert trailing to packed             |
| 33        | CVTWB    | Convert word to byte                   |
| 6D        | CVTWD    | Convert word to D_floating             |
| 4D        | CVTWF    | Convert word to F_floating             |
| 4DFD      | CVTWG    | Convert word to G_floating             |
| 6DFD      | CVTWH    | Convert word to H_floating             |
| 32        | CVTWL    | Convert word to longword               |
| 97        | DECB     | Decrement byte                         |
| D7        | DECL     | Decrement longword                     |
| B7        | DECW     | Decrement word                         |
| 86        | DIVB2    | Divide byte 2 operand                  |
| 87        | DIVB3    | Divide byte 3 operand                  |
| 66        | DIVD2    | Divide D_floating 2 operand            |
| 67        | DIVD3    | Divide D_floating 3 operand            |
| 46        | DIVF2    | Divide F_floating 2 operand            |
| 47        | DIVF3    | Divide F_floating 3 operand            |
| 46FD      | DIVG2    | Divide G_floating 2 operand            |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                        |
|-----------|----------|--|
| 47FD      | DIVG3    | Divide G_floating 3 operand            |
| 66FD      | DIVH2    | Divide H_floating 2 operand            |
| 67FD      | DIVH3    | Divide H_floating 3 operand            |
| C6        | DIVL2    | Divide longword 2 operand              |
| C7        | DIVL3    | Divide longword 3 operand              |
| 27        | DIVP     | Divide packed                          |
| A6        | DIVW2    | Divide word 2 operand                  |
| A7        | DIVW3    | Divide word 3 operand                  |
| 38        | EDITPC   | Edit packed to character               |
| 7B        | EDIV     | Extended divide                        |
| 74        | EMODD    | Extended modulus D_floating            |
| 54        | EMODF    | Extended modulus F_floating            |
| 54FD      | EMODG    | Extended modulus G_floating            |
| 74FD      | EMODH    | Extended modulus H_floating            |
| 7A        | EMUL     | Extended multiply                      |
| EE        | EXTV     | Extract field                          |
| EF        | EXTZV    | Extract zero-extended field            |
| EB        | FFC      | Find first clear bit                   |
| EA        | FFS      | Find first set bit                     |
| 00        | HALT     | Halt                                   |
| 96        | INCB     | Increment byte                         |
| D6        | INCL     | Increment longword                     |
| B6        | INCW     | Increment word                         |
| 0A        | INDEX    | Index calculation                      |
| 5C        | INSQHI   | Insert into queue at head, interlocked |
| 5D        | INSQTI   | Insert into queue at tail, interlocked |
| 0E        | INSQUE   | Insert into queue                      |
| F0        | INSV     | Insert field                           |
| EDFD      | IOTA     | Generate compressed iota vector        |
| 17        | JMP      | Jump                                   |
| 16        | JSB      | Jump to subroutine                     |
| 06        | LDPCTX   | Load program context                   |
| 3A        | LOCC     | Locate character                       |
| 39        | MATCHC   | Match characters                       |
| 92        | MCOMB    | Move complemented byte                 |
| D2        | MCOML    | Move complemented longword             |
| B2        | MCOMW    | Move complemented word                 |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                     |
|-----------|----------|-------------------------------------|
| DB        | MFPR     | Move from processor register        |
| 31FD      | MFVP     | Move from vector processor          |
| 8E        | MNEGB    | Move negated byte                   |
| 72        | MNEGD    | Move negated D_floating             |
| 52        | MNEGF    | Move negated F_floating             |
| 52FD      | MNEGG    | Move negated G_floating             |
| 72FD      | MNEGH    | Move negated H_floating             |
| CE        | MNEGL    | Move negated longword               |
| AE        | MNEGW    | Move negated word                   |
| 9E        | MOVAB    | Move address of byte                |
| 7E        | MOVAD    | Move address of D_floating          |
| DE        | MOVAF    | Move address of F_floating          |
| 7E        | MOVAG    | Move address of G_floating          |
| 7EFD      | MOVAH    | Move address of H_floating          |
| DE        | MOVAL    | Move address of longword            |
| 7EFD      | MOVAO    | Move address of octaword            |
| 7E        | MOVAQ    | Move address of quadword            |
| 3E        | MOVAW    | Move address of word                |
| 90        | MOVB     | Move byte                           |
| 28        | MOV C3   | Move character 3 operand            |
| 2C        | MOV C5   | Move character 5 operand            |
| 70        | MOV D    | Move D_floating                     |
| 50        | MOV F    | Move F_floating                     |
| 50FD      | MOV G    | Move G_floating                     |
| 70FD      | MOV H    | Move H_floating                     |
| D0        | MOV L    | Move longword                       |
| 7DFD      | MOV O    | Move data                           |
| 34        | MOV P    | Move packed                         |
| DC        | MOV PSL  | Move program status longword        |
| 7D        | MOV Q    | Move quadword                       |
| 2E        | MOV TC   | Move translated characters          |
| 2F        | MOV TUC  | Move translated until character     |
| B0        | MOV W    | Move word                           |
| 0A        | MOV ZBL  | Move zero-extended byte to longword |
| 9B        | MOV ZBW  | Move zero-extended byte to word     |
| 3C        | MOV ZWL  | Move zero-extended word to longword |
| DA        | MTPR     | Move to processor register          |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                        |
|-----------|----------|--|
| A9FD      | MTVP     | Move to vector processor               |
| 84        | MULB2    | Multiply byte 2 operand                |
| 85        | MULB3    | Multiply byte 3 operand                |
| 64        | MULD2    | Multiply D_floating 2 operand          |
| 65        | MULD3    | Multiply D_floating 3 operand          |
| 44        | MULF2    | Multiply F_floating 2 operand          |
| 45        | MULF3    | Multiply F_floating 3 operand          |
| 44FD      | MULG2    | Multiply G_floating 2 operand          |
| 45FD      | MULG3    | Multiply G_floating 3 operand          |
| 64FD      | MULH2    | Multiply H_floating 2 operand          |
| 65FD      | MULH3    | Multiply H_floating 3 operand          |
| C4        | MULL2    | Multiply longword 2 operand            |
| C5        | MULL3    | Multiply longword 3 operand            |
| 25        | MULP     | Multiply packed                        |
| A4        | MULW2    | Multiply word 2 operand                |
| A5        | MULW3    | Multiply word 3 operand                |
| 01        | NOP      | No operation                           |
| 75        | POLYD    | Evaluate polynomial D_floating         |
| 55        | POLYF    | Evaluate polynomial F_floating         |
| 55FD      | POLYG    | Evaluate polynomial G_floating         |
| 75FD      | POLYH    | Evaluate polynomial H_floating         |
| BA        | POPR     | Pop registers                          |
| 0C        | PROBER   | Probe read access                      |
| 0D        | PROBEW   | Probe write access                     |
| 9F        | PUSHAB   | Push address of byte                   |
| 7F        | PUSHAD   | Push address of D_floating             |
| DF        | PUSHAF   | Push address of F_floating             |
| 7F        | PUSHAG   | Push address of G_floating             |
| 7FFD      | PUSHAH   | Push address of H_floating             |
| DF        | PUSHAL   | Push address of longword               |
| 7FFD      | PUSHAO   | Push address of octaword               |
| 7F        | PUSHAQ   | Push address of quadword               |
| 3F        | PUSHAW   | Push address of word                   |
| DD        | PUSHL    | Push longword                          |
| BB        | PUSHR    | Push registers                         |
| 02        | REI      | Return from exception or interrupt     |
| 5E        | REMQHI   | Remove from queue at head, interlocked |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                                       |
|-----------|----------|---|
| 5F        | REMQTI   | Remove from queue at tail, interlocked                |
| 0F        | REMQUE   | Remove from queue                                     |
| 04        | RET      | Return from called procedure                          |
| 9C        | ROTL     | Rotate longword                                       |
| 05        | RSB      | Return from subroutine                                |
| D9        | SBWC     | Subtract with carry                                   |
| 2A        | SCANC    | Scan for character                                    |
| 3B        | SKPC     | Skip character  |
| F4        | SOBGEQ   | Subtract one and branch on greater or equal           |
| F5        | SOBGTR   | Subtract one and branch on greater                    |
| 2B        | SPANC    | Span characters                                       |
| 82        | SUBB2    | Subtract byte 2 operand                               |
| 83        | SUBB3    | Subtract byte 3 operand                               |
| 62        | SUBD2    | Subtract D_floating 2 operand                         |
| 63        | SUBD3    | Subtract D_floating 3 operand                         |
| 42        | SUBF2    | Subtract F_floating 2 operand                         |
| 43        | SUBF3    | Subtract F_floating 3 operand                         |
| 42FD      | SUBG2    | Subtract G_floating 2 operand                         |
| 43FD      | SUBG3    | Subtract G_floating 3 operand                         |
| 62FD      | SUBH2    | Subtract H_floating 2 operand                         |
| 63FD      | SUBH3    | Subtract H_floating 3 operand                         |
| C2        | SUBL2    | Subtract longword 2 operand                           |
| C3        | SUBL3    | Subtract longword 3 operand                           |
| 22        | SUBP4    | Subtract packed 4 operand                             |
| 23        | SUBP6    | Subtract packed 6 operand                             |
| A2        | SUBW2    | Subtract word 2 operand                               |
| A3        | SUBW3    | Subtract word 3 operand                               |
| 07        | SVPCTX   | Save process context                                  |
| 95        | TSTB     | Test byte   |
| 73        | TSTD     | Test D_floating                                       |
| 53        | TSTF     | Test F_floating                                       |
| 53FD      | TSTG     | Test G_floating                                       |
| 73FD      | TSTH     | Test H_floating                                       |
| D5        | TSTL     | Test longword   |
| B5        | TSTW     | Test word   |
| 35FD      | VGATHL   | Gather longword vector from memory to vector register |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D–1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name  |
|-----------|----------|--|
| 37FD      | VGATHQ   | Gather quadword vector from memory to vector register  |
| 34FD      | VLDL     | Load longword vector from memory to vector register    |
| 36FD      | VLDQ     | Load quadword vector from memory to vector register    |
| 87FD      | VSADDD   | Vector scalar add D_floating                           |
| 85FD      | VSADDF   | Vector scalar add F_floating                           |
| 83FD      | VSADDG   | Vector scalar add G_floating                           |
| 81FD      | VSADDL   | Vector scalar add longword                             |
| CDFD      | VSBICL   | Vector scalar bit clear longword                       |
| C9FD      | VSBI SL  | Vector scalar bit set longword                         |
| 9DFD      | VSCATL   | Scatter longword vector from vector register to memory |
| 9FFD      | VSCATQ   | Scatter quadword vector from vector register to memory |
| C7FD      | VSCMPD   | Vector scalar compare D_floating                       |
| C5FD      | VSCMPF   | Vector scalar compare F_floating                       |
| C3FD      | VSCMPG   | Vector scalar compare G_floating                       |
| C1FD      | VSCMPL   | Vector scalar compare longword                         |
| AFFD      | VSDIVD   | Vector scalar divide D_floating                        |
| ADFD      | VSDIVF   | Vector scalar divide F_floating                        |
| ABFD      | VSDIVG   | Vector scalar divide G_floating                        |
| EFFD      | VSMERGE  | Vector scalar merge                                    |
| A7FD      | VSMULD   | Vector scalar multiply D_floating                      |
| A5FD      | VSMULF   | Vector scalar multiply F_floating                      |
| A3FD      | VSMULG   | Vector scalar multiply G_floating                      |
| A1FD      | VSMULL   | Vector scalar multiply longword                        |
| E5FD      | VSSLLL   | Vector scalar shift left logical longword              |
| E1FD      | VSSRLL   | Vector scalar shift right logical longword             |
| 8FFD      | VSSUBD   | Vector scalar subtract D_floating                      |
| 8DFD      | VSSUBF   | Vector scalar subtract F_floating                      |
| 8BFD      | VSSUBG   | Vector scalar subtract G_floating                      |
| 89FD      | VSSUBL   | Vector scalar subtract longword                        |
| 9CFD      | VSTL     | Store longword vector from vector register to memory   |
| 9EFD      | VSTQ     | Store quadword vector from vector register to memory   |
| E9FD      | VSXORL   | Vector scalar exclusive-OR longword                    |
| A8FD      | VS YNC   | Synchronize vector memory access                       |
| 86FD      | VVADDD   | Vector vector add D_floating                           |
| 84FD      | VVADDF   | Vector vector add F_floating                           |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D–1 (Cont.) Opcodes (Alphabetic Order) and Functions**

| Hex Value | Mnemonic | Functional Name                            |
|-----------|----------|--|
| 82FD      | VVADDG   | Vector vector add G_floating               |
| 80FD      | VVADDL   | Vector vector add longword                 |
| CCFD      | VVBICL   | Vector vector bit clear longword           |
| C8FD      | VVBISL   | Vector vector bit set longword             |
| C6FD      | VVCMPD   | Vector vector compare D_floating           |
| C4FD      | VVCMPF   | Vector vector compare F_floating           |
| C2FD      | VVCMPG   | Vector vector compare G_floating           |
| C0FD      | VVCMPL   | Vector vector compare longword             |
| ECFD      | VVCVT    | Vector convert                             |
| AEFD      | VVDIVD   | Vector vector divide D_floating            |
| ACFD      | VVDIVF   | Vector vector divide F_floating            |
| AAFD      | VVDIVG   | Vector vector divide G_floating            |
| EEFD      | VVMERGE  | Vector vector merge                        |
| A6FD      | VVMULD   | Vector vector multiply F_floating          |
| A4FD      | VVMULF   | Vector vector multiply F_floating          |
| A2FD      | VVMULG   | Vector vector multiply G_floating          |
| A0FD      | VVMULL   | Vector vector multiply longword            |
| E4FD      | VVSLLL   | Vector vector shift left logical longword  |
| E0FD      | VVSRLl   | Vector vector shift right logical longword |
| 8EFD      | VVSUBD   | Vector vector subtract D_floating          |
| 8CFD      | VVSUBF   | Vector vector subtract F_floating          |
| 8AFD      | VVSUBG   | Vector vector subtract G_floating          |
| 88FD      | VVSUBL   | Vector vector subtract longword            |
| E8FD      | VVXORL   | Vector vector exclusive-OR longword        |
| FC        | XFC      | Extended function call                     |
| 8C        | XORB2    | Exclusive-OR byte 2 operand                |
| 8D        | XORB3    | Exclusive-OR byte 3 operand                |
| CC        | XORL2    | Exclusive-OR longword 2 operand            |
| CD        | XORL3    | Exclusive-OR longword 3 operand            |
| AC        | XORW2    | Exclusive-OR word 2 operand                |
| AD        | XORW3    | Exclusive-OR word 3 operand                |

**Table D–2 One\_Byte Opcodes (Numeric Order)**

| Hex Value | Mnemonic | Hex Value | Mnemonic |
|-----------|----------|-----------|----------|
| 00        | HALT     | 30        | BSBW     |
| 01        | NOP      | 31        | BRW      |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

Table D-2 (Cont.) One\_Byte Opcodes (Numeric Order)

| Hex Value | Mnemonic    | Hex Value | Mnemonic |
|-----------|-------------|-----------|----------|
| 02        | REI         | 32        | CVTWL    |
| 03        | BPT         | 33        | CVTWB    |
| 04        | RET         | 34        | MOVP     |
| 05        | RSB         | 35        | CMPP3    |
| 06        | LDPCTX      | 36        | CVTPL    |
| 07        | SVPCTX      | 37        | CMPP4    |
| 08        | CVTPS       | 38        | EDITPC   |
| 09        | CVTSP       | 39        | MATCHC   |
| 0A        | INDEX       | 3A        | LOCC     |
| 0B        | CRC         | 3B        | SKPC     |
| 0C        | PROBER      | 3C        | MOVZWL   |
| 0D        | PROBEW      | 3D        | ACBW     |
| 0E        | INSQUE      | 3E        | MOVAW    |
| 0F        | REMQUE      | 3F        | PUSHAW   |
| 10        | BSBB        | 40        | ADDF2    |
| 11        | BRB         | 41        | ADDF3    |
| 12        | BNEQ, BNEQU | 42        | SUBF2    |
| 13        | BEQL, BEQLU | 43        | SUBF3    |
| 14        | BGTR        | 44        | MULF2    |
| 15        | BLEQ        | 45        | MULF3    |
| 16        | JSB         | 46        | DIVF2    |
| 17        | JMP         | 47        | DIVF3    |
| 18        | BGEQ        | 48        | CVTFB    |
| 19        | BLSS        | 49        | CVTFW    |
| 1A        | BGTRU       | 4A        | CVTFL    |
| 1B        | BLEQU       | 4B        | CVTRFL   |
| 1C        | BVC         | 4C        | CVTBF    |
| 1D        | BVS         | 4D        | CVTWF    |
| 1E        | BGEQU, BCC  | 4E        | CVTLF    |
| 1F        | BLSSU, BCS  | 4F        | ACBF     |
| 20        | ADDP4       | 50        | MOVF     |
| 21        | ADDP6       | 51        | CMPF     |
| 22        | SUBP4       | 52        | MNEGF    |
| 23        | SUBP6       | 53        | TSTF     |
| 24        | CVTPT       | 54        | EMODF    |
| 25        | MULP        | 55        | POLYF    |
| 26        | CVTTP       | 56        | CVTFD    |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-2 (Cont.) One\_Byte Opcodes (Numeric Order)**

| Hex Value | Mnemonic           | Hex Value | Mnemonic           |
|-----------|--------------------|-----------|--------------------|
| 27        | DIVP               | 57        | Reserved to Compaq |
| 28        | MOVC3              | 58        | ADAWI              |
| 29        | CMPC3              | 59        | Reserved to Compaq |
| 2A        | SCANC              | 5A        | Reserved to Compaq |
| 2B        | SPANC              | 5B        | Reserved to Compaq |
| 2C        | MOVC5              | 5C        | INSQHI             |
| 2D        | CMPC5              | 5D        | INSQTI             |
| 2E        | MOVTC              | 5E        | REMQHI             |
| 2F        | MOVTUC             | 5F        | REMQTI             |
| 60        | ADDD2              | 90        | MOVB               |
| 61        | ADDD3              | 91        | CMPB               |
| 62        | SUBD2              | 92        | MCOMB              |
| 63        | SUBD3              | 93        | BITB               |
| 64        | MULD2              | 94        | CLRB               |
| 65        | MULD3              | 95        | TSTB               |
| 66        | DIVD2              | 96        | INCB               |
| 67        | DIVD3              | 97        | DECB               |
| 68        | CVTDB              | 98        | CVTBL              |
| 69        | CVTDW              | 99        | CVTBW              |
| 6A        | CVTDL              | 9A        | MOVZBL             |
| 6B        | CVTRDL             | 9B        | MOVZBW             |
| 6C        | CVTBD              | 9C        | ROTL               |
| 6D        | CVTWD              | 9D        | ACBB               |
| 6E        | CVTLD              | 9E        | MOVAB              |
| 6F        | ACBD               | 9F        | PUSHAB             |
| 70        | MOVD               | A0        | ADDW2              |
| 71        | CMPD               | A1        | ADDW3              |
| 72        | MNEGD              | A2        | SUBW2              |
| 73        | TSTD               | A3        | SUBW3              |
| 74        | EMODD              | A4        | MULW2              |
| 75        | POLYD              | A5        | MULW3              |
| 76        | CVTDF              | A6        | DIVW2              |
| 77        | Reserved to Compaq | A7        | DIVW3              |
| 78        | ASHL               | A8        | BISW2              |
| 79        | ASHQ               | A9        | BISW3              |
| 7A        | EMUL               | AA        | BICW2              |
| 7B        | EDIV               | AB        | BICW3              |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

Table D-2 (Cont.) One\_Byte Opcodes (Numeric Order)

| Hex Value | Mnemonic               | Hex Value | Mnemonic |
|-----------|------------------------|-----------|----------|
| 7C        | CLRQ, CLRD, CLRG       | AC        | XORW2    |
| 7D        | MOVQ                   | AD        | XORW3    |
| 7E        | MOVAQ, MOVAD, MOVAG    | AE        | MNEGW    |
| 7F        | PUSHAQ, PUSHAD, PUSHAG | AF        | CASEW    |
| 80        | ADDB2                  | B0        | MOVW     |
| 81        | ADDB3                  | B1        | CMPW     |
| 82        | SUBB2                  | B2        | MCOMW    |
| 83        | SUBB3                  | B3        | BITW     |
| 84        | MULB2                  | B4        | CLRW     |
| 85        | MULB3                  | B5        | TSTW     |
| 86        | DIVB2                  | B6        | INCW     |
| 87        | DIVB3                  | B7        | DECW     |
| 88        | BISB2                  | B8        | BISPSW   |
| 89        | BISB3                  | B9        | BICPSW   |
| 8A        | BICB2                  | BA        | POPR     |
| 8B        | BICB3                  | BB        | PUSHR    |
| 8C        | XORB2                  | BC        | CHMK     |
| 8D        | XORB3                  | BD        | CHME     |
| 8E        | MNEGB                  | BE        | CHMS     |
| 8F        | CASEB                  | BF        | CHMU     |
| C0        | ADDL2                  | E0        | BBS      |
| C1        | ADDL3                  | E1        | BBC      |
| C2        | SUBL2                  | E2        | BBSS     |
| C3        | SUBL3                  | E3        | BBCS     |
| C4        | MULL2                  | E4        | BBSC     |
| C5        | MULL3                  | E5        | BBCC     |
| C6        | DIVL2                  | E6        | BBSSI    |
| C7        | DIVL3                  | E7        | BBCCI    |
| C8        | BISL2                  | E8        | BLBS     |
| C9        | BISL3                  | E9        | BLBC     |
| CA        | BICL2                  | EA        | FFS      |
| CB        | BICL3                  | EB        | FFC      |
| CC        | XORL2                  | EC        | CMPV     |
| CD        | XORL3                  | ED        | CMPZV    |
| CE        | MNEGL                  | EE        | EXTV     |
| CF        | CASEL                  | EF        | EXTZV    |
| D0        | MOVL                   | F0        | INSV     |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-2 (Cont.) One\_Byte Opcodes (Numeric Order)**

| Hex Value | Mnemonic       | Hex Value | Mnemonic       |
|-----------|----------------|-----------|----------------|
| D1        | CMPL           | F1        | ACBL           |
| D2        | MCOML          | F2        | AOBLSS         |
| D3        | BITL           | F3        | AOBLEQ         |
| D4        | CLRL, CLRF     | F4        | SOBGEQ         |
| D5        | TSTL           | F5        | SOBGTR         |
| D6        | INCL           | F6        | CVTLB          |
| D7        | DECL           | F7        | CVTLW          |
| D8        | ADWC           | F8        | ASHP           |
| D9        | SBWC           | F9        | CVTLP          |
| DA        | MTPR           | FA        | CALLG          |
| DB        | MFPR           | FB        | CALLS          |
| DC        | MOVPSL         | FC        | XFC            |
| DD        | PUSHL          | FD        | ESCD to Compaq |
| DE        | MOVAL, MOVA    | FE        | ESCE to Compaq |
| DF        | PUSHAL, PUSHAF | FF        | ESCF to Compaq |

**Table D-3 Two\_Byte Opcodes (Numeric Order)**

| Hex Value | Mnemonic           | Hex Value | Mnemonic           |
|-----------|--------------------|-----------|--------------------|
| 00FD      | Reserved to Compaq | 30FD      | Reserved to Compaq |
| 01FD      | Reserved to Compaq | 31FD      | MFVP               |
| 02FD      | Reserved to Compaq | 32FD      | CVTDH              |
| 03FD      | Reserved to Compaq | 33FD      | CVTGF              |
| 04FD      | Reserved to Compaq | 34FD      | VLDL               |
| 05FD      | Reserved to Compaq | 35FD      | VGATHL             |
| 06FD      | Reserved to Compaq | 36FD      | VLDQ               |
| 07FD      | Reserved to Compaq | 37FD      | VGATHQ             |
| 08FD      | Reserved to Compaq | 38FD      | Reserved to Compaq |
| 09FD      | Reserved to Compaq | 39FD      | Reserved to Compaq |
| 0AFD      | Reserved to Compaq | 3AFD      | Reserved to Compaq |
| 0BFD      | Reserved to Compaq | 3BFD      | Reserved to Compaq |
| 0CFD      | Reserved to Compaq | 3CFD      | Reserved to Compaq |
| 0DFD      | Reserved to Compaq | 3DFD      | Reserved to Compaq |
| 0EFD      | Reserved to Compaq | 3EFD      | Reserved to Compaq |
| 0FFD      | Reserved to Compaq | 3FFD      | Reserved to Compaq |
| 10FD      | Reserved to Compaq | 40FD      | ADDG2              |
| 11FD      | Reserved to Compaq | 41FD      | ADDG3              |

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## Permanent Symbol Table Defined for Use with VAX MACRO

Table D-3 (Cont.) Two\_Byte Opcodes (Numeric Order)

| Hex Value | Mnemonic           | Hex Value | Mnemonic           |
|-----------|--------------------|-----------|--------------------|
| 12FD      | Reserved to Compaq | 42FD      | SUBG2              |
| 13FD      | Reserved to Compaq | 43FD      | SUBG3              |
| 14FD      | Reserved to Compaq | 44FD      | MULG2              |
| 15FD      | Reserved to Compaq | 45FD      | MULG3              |
| 16FD      | Reserved to Compaq | 46FD      | DIVG2              |
| 17FD      | Reserved to Compaq | 47FD      | DIVG3              |
| 18FD      | Reserved to Compaq | 48FD      | CVTGB              |
| 19FD      | Reserved to Compaq | 49FD      | CVTGW              |
| 1AFD      | Reserved to Compaq | 4AFD      | CVTGL              |
| 1BFD      | Reserved to Compaq | 4BFD      | CVTRGL             |
| 1CFD      | Reserved to Compaq | 4CFD      | CVTBG              |
| 1DFD      | Reserved to Compaq | 4DFD      | CVTWG              |
| 1EFD      | Reserved to Compaq | 4EFD      | CVTLG              |
| 1FFD      | Reserved to Compaq | 4FFD      | ACBG               |
| 20FD      | Reserved to Compaq | 50FD      | MOVG               |
| 21FD      | Reserved to Compaq | 51FD      | CMPG               |
| 22FD      | Reserved to Compaq | 52FD      | MNEGG              |
| 23FD      | Reserved to Compaq | 53FD      | TSTG               |
| 24FD      | Reserved to Compaq | 54FD      | EMODG              |
| 25FD      | Reserved to Compaq | 55FD      | POLYG              |
| 26FD      | Reserved to Compaq | 56FD      | CVTGH              |
| 27FD      | Reserved to Compaq | 57FD      | Reserved to Compaq |
| 28FD      | Reserved to Compaq | 58FD      | Reserved to Compaq |
| 29FD      | Reserved to Compaq | 59FD      | Reserved to Compaq |
| 2AFD      | Reserved to Compaq | 5AFD      | Reserved to Compaq |
| 2BFD      | Reserved to Compaq | 5BFD      | Reserved to Compaq |
| 2CFD      | Reserved to Compaq | 5CFD      | Reserved to Compaq |
| 2DFD      | Reserved to Compaq | 5DFD      | Reserved to Compaq |
| 2EFD      | Reserved to Compaq | 5EFD      | Reserved to Compaq |
| 2FFD      | Reserved to Compaq | 5FFD      | Reserved to Compaq |
| 60FD      | ADDH2              | 90FD      | Reserved to Compaq |
| 61FD      | ADDH3              | 91FD      | Reserved to Compaq |
| 62FD      | SUBH2              | 92FD      | Reserved to Compaq |
| 63FD      | SUBH3              | 93FD      | Reserved to Compaq |
| 64FD      | MULH2              | 94FD      | Reserved to Compaq |
| 65FD      | MULH3              | 95FD      | Reserved to Compaq |
| 66FD      | DIVH2              | 96FD      | Reserved to Compaq |

(continued on next page)

## Permanent Symbol Table Defined for Use with VAX MACRO

**Table D-3 (Cont.) Two\_Byte Opcodes (Numeric Order)**

| Hex Value | Mnemonic           | Hex Value | Mnemonic           |
|-----------|--------------------|-----------|--------------------|
| 67FD      | DIVH3              | 97FD      | Reserved to Compaq |
| 68FD      | CVTHB              | 98FD      | CVTFH              |
| 69FD      | CVTHW              | 99FD      | CVTFG              |
| 6AFD      | CVTHL              | 9AFD      | Reserved to Compaq |
| 6BFD      | CVTRHL             | 9BFD      | Reserved to Compaq |
| 6CFD      | CVTBH              | 9CFD      | VSTL               |
| 6DFD      | CVTWH              | 9DFD      | VSCATL             |
| 6EFD      | CVTLH              | 9EFD      | VSTQ               |
| 6FFD      | ACBH               | 9FFD      | VSCATQ             |
| 70FD      | MOVH               | A0FD      | VVMULL             |
| 71FD      | CMPH               | A1FD      | VSMULL             |
| 72FD      | MNEGH              | A2FD      | VVMULG             |
| 73FD      | TSTH               | A3FD      | VSMULG             |
| 74FD      | EMODH              | A4FD      | VVMULF             |
| 75FD      | POLYH              | A5FD      | VSMULF             |
| 76FD      | CVTHG              | A6FD      | VVMULD             |
| 77FD      | Reserved to Compaq | A7FD      | VSMULD             |
| 78FD      | Reserved to Compaq | A8FD      | VSYNC              |
| 79FD      | Reserved to Compaq | A9FD      | MTVP               |
| 7AFD      | Reserved to Compaq | AAF       | VVDIVG             |
| 7BFD      | Reserved to Compaq | ABFD      | VSDIVG             |
| 7CFD      | CLRH, CLRO         | ACFD      | VVDIVF             |
| 7DFD      | MOV0               | ADFD      | VSDIVF             |
| 7EFD      | MOVAH, MOVAO       | AEDF      | VVDIVD             |
| 7FFD      | PUSHAH, PUSHAO     | AFFD      | VSDIVD             |
| 80FD      | VVADDL             | B0FD      | Reserved to Compaq |
| 81FD      | VSADDL             | B1FD      | Reserved to Compaq |
| 82FD      | VVADDG             | B2FD      | Reserved to Compaq |
| 83FD      | VSADDG             | B3FD      | Reserved to Compaq |
| 84FD      | VVADDF             | B4FD      | Reserved to Compaq |
| 85FD      | VSADDF             | B5FD      | Reserved to Compaq |
| 86FD      | VVADDD             | B6FD      | Reserved to Compaq |
| 87FD      | VSADDD             | B7FD      | Reserved to Compaq |
| 88FD      | VVSUBL             | B8FD      | Reserved to Compaq |
| 89FD      | VSSUBL             | B9FD      | Reserved to Compaq |
| 8AFD      | VVSUBG             | BAFD      | Reserved to Compaq |
| 8BFD      | VSSUBG             | BBFD      | Reserved to Compaq |

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## Permanent Symbol Table Defined for Use with VAX MACRO

Table D-3 (Cont.) Two\_Byte Opcodes (Numeric Order)

| Hex Value | Mnemonic              | Hex Value | Mnemonic              |
|-----------|-----------------------|-----------|-----------------------|
| 8CFD      | VVSUBF                | BCFD      | Reserved to Compaq    |
| 8DFD      | VSSUBF                | BDFD      | Reserved to Compaq    |
| 8EFD      | VVSUBD                | BEFD      | Reserved to Compaq    |
| 8FFD      | VSSUBD                | BFFD      | Reserved to Compaq    |
| C0FD      | VVCMPPL               | E0FD      | VVSRLI                |
| C1FD      | VSCMPL                | E1FD      | VSSRLI                |
| C2FD      | VVCMPG                | E2FD      | Illegal Vector Opcode |
| C3FD      | VSCMPG                | E3FD      | Illegal Vector Opcode |
| C4FD      | VVCMPF                | E4FD      | VVSLLI                |
| C5FD      | VSCMPF                | E5FD      | VSSLLI                |
| C6FD      | VVCMPD                | E6FD      | Illegal Vector Opcode |
| C7FD      | VSCMPD                | E7FD      | Illegal Vector Opcode |
| C8FD      | VVBISL                | E8FD      | VVXORL                |
| C9FD      | VSBISL                | E9FD      | VSXORL                |
| CAFD      | Illegal Vector Opcode | EAFD      | Illegal Vector Opcode |
| CBFD      | Illegal Vector Opcode | EBFD      | Illegal Vector Opcode |
| CCFD      | VVBICL                | ECFD      | VVCVT                 |
| CDFD      | VSBICL                | EDFD      | IOTA                  |
| CEFD      | Illegal Vector Opcode | EEFD      | VVMERGE               |
| CFFD      | Illegal Vector Opcode | EFFD      | VSMERGE               |
| D0FD      | Reserved to Compaq    | F0FD      | Reserved to Compaq    |
| D1FD      | Reserved to Compaq    | F1FD      | Reserved to Compaq    |
| D2FD      | Reserved to Compaq    | F2FD      | Reserved to Compaq    |
| D3FD      | Reserved to Compaq    | F3FD      | Reserved to Compaq    |
| D4FD      | Reserved to Compaq    | F4FD      | Reserved to Compaq    |
| D5FD      | Reserved to Compaq    | F5FD      | Reserved to Compaq    |
| D6FD      | Reserved to Compaq    | F6FD      | CVTHF                 |
| D7FD      | Reserved to Compaq    | F7FD      | CVTHD                 |
| D8FD      | Reserved to Compaq    | F8FD      | Reserved to Compaq    |
| D9FD      | Reserved to Compaq    | F9FD      | Reserved to Compaq    |
| DAFD      | Reserved to Compaq    | FAFD      | Reserved to Compaq    |
| DBFD      | Reserved to Compaq    | FBFD      | Reserved to Compaq    |
| DCFD      | Reserved to Compaq    | FCFD      | Reserved to Compaq    |
| DDFD      | Reserved to Compaq    | FCFE      | Reserved to Compaq    |

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## Permanent Symbol Table Defined for Use with VAX MACRO

Table D-3 (Cont.) Two\_Byte Opcodes (Numeric Order)

| Hex Value | Mnemonic           | Hex Value | Mnemonic              |
|-----------|--------------------|-----------|-----------------------|
| DEFD      | Reserved to Compaq | FCFF      | Reserved to Compaq    |
| DFFD      | Reserved to Compaq | FDFD      | BUGL                  |
|           |                    | FEFF      | BUGW                  |
|           |                    | FFFF      | Reserved for all time |



## Exceptions That May Occur During Instruction Execution

Exceptions can be grouped into the following six classes:

- Arithmetic traps and faults
- Memory management exceptions
- Exceptions detected during operand reference
- Tracing
- Serious system failures

### E.1 Arithmetic Traps and Faults

This section contains the descriptions of the exceptions that occur as the result of performing an arithmetic or conversion operation. They are mutually exclusive and are all assigned the same vector in the system control block (SCB) and the same signal “reason” code. Each exception indicates that an instruction has been completed (trap) or backed up (fault). An appropriate distinguishing exception type code is pushed onto the stack as a longword. Table E-1 lists the arithmetic exception type codes.

**Table E-1 Arithmetic Exception Type Codes**

| Exception Type                     | Mnemonic      | Decimal Value | Hexadecimal Value |
|------------------------------------|---------------|---------------|-------------------|
| <b>Traps</b>                       |               |               |                   |
| integer overflow                   | SS\$ INTOVF   | 1             | 1                 |
| integer divide-by-zero             | SS\$ INTDIV   | 2             | 2                 |
| floating overflow                  | SS\$ FLTOVF   | 3             | 3                 |
| floating or decimal divide-by-zero | SS\$ FLTDIV   | 4             | 4                 |
| floating underflow                 | SS\$ FLTUND   | 5             | 5                 |
| decimal overflow                   | SS\$ DECOVF   | 6             | 6                 |
| subscript range                    | SS\$ SUBRNG   | 7             | 7                 |
| <b>Faults</b>                      |               |               |                   |
| floating underflow                 | SS\$ FLTOVF_F | 8             | 8                 |
| floating divide-by-zero            | SS\$ FLTDIV_F | 9             | 9                 |

(continued on next page)

## Exceptions That May Occur During Instruction Execution

### E.1 Arithmetic Traps and Faults

Table E-1 (Cont.) Arithmetic Exception Type Codes

| Exception Type     | Mnemonic     | Decimal Value | Hexadecimal Value |
|--------------------|--------------|---------------|-------------------|
| floating underflow | SS\$FLTUND_F | 10            | A                 |

#### E.1.1 Integer Overflow Trap

An integer overflow trap is an exception indicating that the last instruction executed had an integer overflow, which set the processor status longword (PSL) V bit, and that the integer overflow was enabled (the IV bit in the PSL was set). The stored result is the low-order part of the correct result. The N and Z bits in the PSL are set according to the stored result. The type code pushed onto the stack is 1 (SS\$INTOVF).

#### E.1.2 Integer Divide-by-Zero Trap

An integer divide-by-zero trap is an exception indicating that the last instruction executed had an integer zero divisor. The stored result is equal to the dividend, and condition code V bit in the PSL is set. The type code pushed onto the stack is 2 (SS\$INTDIV).

#### E.1.3 Floating Overflow Trap

A floating overflow trap is an exception indicating that the last instruction executed resulted in an exponent greater than the largest representable exponent for the data type after normalization and rounding. The stored result contains a one in the sign field and zeros in the exponent and fraction fields. This is a reserved operand. It causes a reserved operand fault if used in a subsequent floating-point instruction. The N and V condition code bits in the PSL are set, and the Z and C bits in the PSL are cleared. The type code pushed onto the stack is 3 (SS\$FLTTOVF).

#### E.1.4 Divide-by-Zero Trap

A floating divide-by-zero trap is an exception indicating that the last instruction executed had a floating zero divisor. The stored result is the reserved operand described previously for the floating overflow trap. The condition codes are set as they are for the floating overflow trap.

A decimal string divide-by-zero trap is an exception indicating that the last instruction executed had a decimal-string zero divisor. The destination, R0 to R5, and condition codes are UNPREDICTABLE. The zero divisor can be either +0 or -0.

The type code pushed onto the stack for both types of divide-by-zero is 4 (SS\$FLTDIV).

#### E.1.5 Floating Underflow Trap

A floating underflow trap is an exception indicating that the last instruction executed resulted in an exponent less than the smallest representable exponent for the data type after normalization and rounding, and that floating underflow was enabled (FU set). The stored result is zero. The N, V, and C condition codes bits in the PSL are cleared, and the Z bit in the PSL is set, except for the polynomial evaluation instruction POLYx. In POLYx, the trap occurs on completion of the instruction, which may be many operations after the underflow.

## Exceptions That May Occur During Instruction Execution

### E.1 Arithmetic Traps and Faults

The condition codes are set on the final result in POLYx. The type code pushed onto the stack is 5 (SS\$FLTUND).

#### E.1.6 Decimal String Overflow Trap

A decimal string overflow trap is an exception indicating that the last instruction executed had a decimal-string result too large for the destination string provided, and that decimal overflow was enabled (the DV bit in the PSL was set). The V condition code bit in the PSL is always set. The type code pushed onto the stack is 6 (SS\$\_DECOVF).

#### E.1.7 Subscript-Range Trap

A subscript range trap is an exception indicating that the last instruction was an INDEX instruction with a subscript operand that failed the range check. The value of the subscript operand is lower than the low operand or greater than the high operand. The result is stored in indexout, and the condition codes are set as if the subscript were within range. The type code pushed onto the stack is 7 (SS\$\_SUBRNG).

#### E.1.8 Floating Overflow Fault

A floating overflow fault is an exception indicating that the last instruction executed resulted in an exponent greater than the largest representable exponent for the data type after normalization and rounding. The destination was unaffected, and the saved condition codes are UNPREDICTABLE. The saved program counter (PC) points to the instruction causing the fault. The POLYx instruction is suspended with the first-part-done bit (FPD) set. The type code pushed onto the stack is 8 (SS\$\_FLTOVF\_F).

#### E.1.9 Divide-by-Zero Floating Fault

A floating divide-by-zero fault is an exception indicating that the last instruction executed had a floating zero divisor. The quotient operand was unaffected and the saved condition codes are UNPREDICTABLE. The saved PC points to the instruction causing the fault. The type code pushed onto the stack is 9 (SS\$\_FLTDIV\_F).

#### E.1.10 Floating Underflow Fault

A floating underflow fault is an exception indicating that the last instruction executed resulted in an exponent less than the smallest representable exponent for the data type after normalization and rounding, and that floating underflow was enabled (the FU bit was set). The destination operand is unaffected. The saved condition codes are UNPREDICTABLE. The saved PC points to the instruction causing the fault. The POLYx instruction is suspended with FPD set. The type code pushed onto the stack is 10 (SS\$\_FLTUND\_F).

## E.2 Memory Management Exceptions

A memory management exception can be either an access control violation fault or a translation not valid fault.

#### E.2.1 Access Control Violation Fault

An access control violation fault is an exception indicating that the process attempted a reference not allowed at the current access mode.

## Exceptions That May Occur During Instruction Execution

### E.2 Memory Management Exceptions

#### E.2.2 Translation Not Valid Fault

A translation not valid fault is an exception indicating that the process attempted a reference to a page for which the valid bit in the page table had not been set.

Note that if a process attempts to reference a page for which the page table entry specifies both translation not valid fault and access control violation, an access control violation fault occurs.

### E.3 Exceptions Detected During Operand Reference

Two exceptions are possible during operand reference: the reserved addressing mode fault and the reserved operand exception.

#### E.3.1 Reserved Addressing Mode Fault

A reserved addressing mode fault is an exception indicating that an operand specifier attempted to use an addressing mode that is disallowed. No parameters are pushed.

#### E.3.2 Reserved Operand Exception

A reserved operand exception is an exception indicating that an accessed operand has a format reserved for future use by Compaq. No parameters are pushed onto the stack. This exception always backs up the saved PC to point to the opcode. The exception service routine may determine the type of operand by examining the opcode using the saved PC.

Note that only the changes made by instruction fetch and the changes made because of operand specifier evaluation may be restored. Therefore, some instructions are not restartable. These exceptions are labeled as aborts rather than as faults. The saved PC is always restored properly unless the instruction attempted to modify it in a manner that results in UNPREDICTABLE results.

The reserved operand exceptions are caused by the following:

- Bit field too wide
- Invalid combination of bits in PSL restored by the return from interrupt (REI) instruction (fault)
- Invalid combination of bits in PSW mask longword during a return from procedure (RET) instruction (fault)
- Invalid combination of bits in the bit set PSW (BISPSW) or bit clear PSW (BICPSW) instructions (fault)
- Invalid call procedure with stack argument list (CALLS) or call procedure with general argument list (CALLG) instructions entry mask (fault)
- Invalid register number in the move from processor register (MFPR) instruction or move to processor register (MTPR) instruction (fault)
- Invalid PCB contents in the load processor context (LDPCTX) instruction for some implementations (abort)
- Unaligned operand in the add aligned word interlocked (ADAWI) instruction (fault)
- Invalid register contents in the move to processor register (MTPR) instruction for some implementations (fault)
- Invalid operand addresses in insert and remove queue interlocked (INSQHI, INSQTI, REMQHI, or REMQTI) instructions (fault)

## Exceptions That May Occur During Instruction Execution

### E.3 Exceptions Detected During Operand Reference

- A floating-point number that has the sign bit set and the exponent zero in the polynomial evaluation (POLY) instruction table (fault)
- POLY degree too large (fault)
- Decimal string too long (abort)
- Invalid digit in convert trailing numeric to packed (CVTTP) or convert separate numeric to packed (CVTSP) instructions (abort)
- Reserved pattern operator in the edit packed to character string (EDITPC) instruction (fault)
- Incorrect source string length at completion of EDITPC (abort)

### E.4 Exceptions Occurring as the Consequence of an Instruction

The following exceptions may occur as a consequence of instruction execution:

- Reserved or privileged instruction fault
- Opcode reserved to customers fault
- Instruction emulation exceptions
- Compatibility mode exception
- Change mode trap
- Breakpoint fault

Each is described in the following subsections.

#### E.4.1 Reserved or Privileged Instruction Fault

A reserved or privileged instruction fault occurs when the processor encounters an opcode that is not specifically defined or requires higher privileges than the current mode. No parameters are pushed onto the stack. Opcode FFFF (hex) will always fault.

#### E.4.2 Operand Reserved to Customers Fault

An opcode reserved to customers fault is an exception that occurs when an opcode reserved to customers is executed. The operation is identical to the reserved or privileged instruction fault, except that the event is caused by a different set of opcodes and faults through a different vector. All opcodes reserved to customers start with FC (hex), which is the XFC instruction. If the special instruction must generate a unique exception, one of the reserved-to-customer vectors should be used. An example might be an unrecognized second byte of the instruction.

The XFC fault is intended primarily for use with writable control store to implement installation-dependent instructions. The method used to enable and disable the handling of an XFC fault in user-written microcode is implementation dependent. Some implementations may transfer control to microcode without checking bits <1:0> of the exception vector.

## Exceptions That May Occur During Instruction Execution

### E.4 Exceptions Occurring as the Consequence of an Instruction

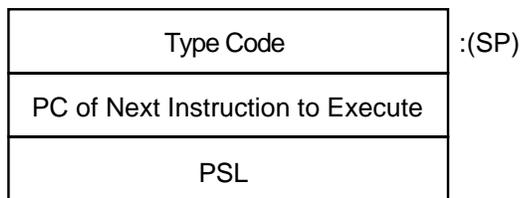
#### E.4.3 Instruction Emulation Exceptions

When a subset processor executes a string instruction that is omitted from its instruction set, an emulation exception results. An emulation exception can occur through either of two system control block (SCB) vectors, depending on whether or not the first-part-done (FPD) bit in the program status longword was set at the beginning of the instruction. If the FPD bit is clear, a subset emulation trap occurs through the SCB vector at offset CB (hex), and a subset emulation trap frame is pushed onto the current stack. If the FPD bit is set, a suspended emulation fault occurs through the SCB vector at offset CC (hex), and the PC and the PSL are pushed onto the current stack.

#### E.4.4 Compatibility Mode Exception

A compatibility mode exception is an exception that occurs when the processor is in compatibility mode. A longword of information containing a code that indicates the exception type is pushed onto the stack. Figure E-1 shows the stack frame, which is the same as that for arithmetic exceptions.

**Figure E-1 Compatibility Mode Exception Stack Frame**



ZK-6351-GE

The compatibility type codes are shown in Table E-2.

**Table E-2 Compatibility Mode Exception Type Codes**

| Exception Type      | Decimal Value |
|---------------------|---------------|
| Faults              |               |
| reserved opcode     | 0             |
| BPT instruction     | 1             |
| IOT instruction     | 2             |
| EMT instruction     | 3             |
| TRAP instruction    | 4             |
| illegal instruction | 5             |
| Aborts              |               |
| odd address         | 6             |

All other exceptions in compatibility mode, including the access control violation fault, the translation not valid fault, and the machine check abort, occur by means of the regular native-mode vector.

## Exceptions That May Occur During Instruction Execution

### E.4 Exceptions Occurring as the Consequence of an Instruction

#### E.4.5 Change Mode Trap

A change mode trap is an exception occurring when one of the change mode instructions (CHMK, CHME, CHMS, or CHMU) is executed. The instruction operand is pushed onto the exception stack.

#### E.4.6 Breakpoint Fault

A breakpoint fault is an exception that occurs when the breakpoint instruction (BPT) is executed. The BPT instruction pushes the current PSL onto the stack.

To proceed from a breakpoint fault, a debugger or tracing program does the following:

1. Restores the original contents of the location containing the BPT instruction.
2. Sets the T bit in the PSL saved by the BPT fault. The PSL is on the stack.
3. Resumes operation of the main instruction stream.

When the instruction that has a breakpoint completes execution, a *trace exception* occurs. At this point, the tracing program takes control and does the following:

1. Reinserts the BPT instruction.
2. Restores the T bit to its original state (usually zero).
3. Resumes operation of the main instruction stream.

Note that if both tracing and breakpointing are in progress (if the PSL T bit was set at the time of the BPT), both the BPT restoration and a normal trace exception should be processed on the trace exception by the trace handler.

### E.5 Trace Fault

Program tracing is used for many purposes. Debugging programs and evaluating program performance are the most common uses of program tracing.

A trace fault is an exception that occurs between instructions when trace is enabled. One trace fault occurs before the execution of each traced instruction. The address in the PC saved when a trace fault occurs is the address of the instruction after the trace fault that would normally be executed. The trace exception for an instruction takes precedence over all other exceptions. The detection of reserved instruction faults occurs after the trace fault. If a trace fault and a memory management fault (or an odd address abort during a compatibility mode instruction fetch) occur simultaneously, exceptions are taken in UNPREDICTABLE order.

To ensure that exactly one trace occurs per instruction despite other traps and faults, the PSL contains the trace enable (T) and trace pending (TP) bits.

The PSL TP bit generates a fault before any other processing at the start of the next instruction.

The following are rules of operation for trace:

1. At the beginning of an instruction, if the trace pending (TP) bit is set, it is cleared and a trace fault is taken.
2. The value of the trace enable (T) bit is loaded into the trace pending (TP) bit.

## Exceptions That May Occur During Instruction Execution

### E.5 Trace Fault

3. The detection of interrupts and other exceptions can occur during instruction execution. In this case, TP is cleared before the exception or interrupt is initiated. The system saves the entire PSL including the T bit and TP bit on interrupt or exception initiation and restores the PSL at the end with an REI. This makes interrupts and benign exceptions totally transparent to the executing program.

The following are conditions and results that might occur during instruction execution or before the next instruction:

- a. If the instruction faults or an interrupt is serviced, the PSL TP bit is cleared before the PSL is saved on the stack. The saved PC (the next lower word on the stack after the saved PSL) is set to the start of the faulting or interrupted instruction. Instruction execution is resumed at step 1.
- b. If the instruction aborts or takes an arithmetic trap, the PSL TP bit is not changed before the PSL is saved on the stack.
- c. If an interrupt is serviced after instruction completion and arithmetic traps but before the presence of tracing is checked at the start of the next instruction, the PSL TP bit is not changed before the PSL is saved on the stack.

#### E.5.1 Trace Operation When Entering a Change Mode Instruction

The routine entered by a change mode (CHMx) instruction is not traced because change mode clears T and TP in the new PSL that is used for whichever new mode is entered. However, if the T bit was set in the old PSW (the one to be saved) at the beginning of the change mode instruction, the system sets both the T and the TP bit in the saved PSL. Trace faults resume with the instruction that follows other returns from interrupt (REI) in the routine entered by the CHMx instruction. An instruction following an REI faults if T was set when the REI was executed, or if the TP bit in the saved PSL is set. In both cases, TP is set after the REI.

#### E.5.2 Trace Operation Upon Return From Interrupt

Note that a trace fault that occurs for an instruction following an REI instruction that had set the TP will be taken with the new PSL restored by the REI instruction. Thus, special care must be taken if exception or interrupt routines are traced.

#### E.5.3 Trace Operation After a BISPSW Instruction

If the T bit is set by a BISPSW instruction, trace faults begin with the second instruction after the BISPSW.

#### E.5.4 Trace Operation After a CALLS or CALLG Instruction

The CALLS and CALLG instructions save a clear T bit, although the T bit in the PSL is unchanged. This is done so that a debugger or trace program proceeding from a BPT fault does not get a spurious trace from the RET that matches the CALL.

## **E.6 Serious System Failures**

The following are possible serious system failures:

- Kernel stack not valid abort
- Interrupt stack not valid halt
- Machine check exception

These system failures are described in the following sections.

### **E.6.1 Kernel Stack Not Valid Abort**

The kernel stack not valid abort is an exception indicating that the kernel stack was not valid while the processor was pushing information onto it during the initiation of an exception or interrupt. This is usually an indication of a stack overflow or other operating system error. During this process, the attempted exception is transformed into an abort that uses the interrupt stack. Only the PSL and PC of the original exception are pushed onto the interrupt stack. The interrupt priority level (IPL) is raised to 1F (hex). If the exception vector bits <1:0> are not both 1, the operation of the processor is UNDEFINED.

Software can abort the process without aborting the system. However, because of the lost information, the process cannot be continued. If the kernel stack is not valid during the normal execution of an instruction (including CHMx or REI), the normal memory management fault is initiated.

### **E.6.2 Interrupt Stack Not Valid Halt**

An interrupt stack not valid halt results when the interrupt stack was not valid or a memory error occurred while the processor was pushing information onto the interrupt stack during the initiation of an exception or interrupt. No further interrupt requests are acknowledged on the processor. The processor leaves the PC, the PSL, and the reason for the halt in registers so that they are available to a debugger, to the normal bootstrap routine, or to an optional watchdog bootstrap routine. A watchdog bootstrap routine can cause the processor to leave the halted state.

### **E.6.3 Machine Check Exception**

A machine check exception indicates that the processor detected an internal error. As is usual for exceptions, a machine check is taken regardless of current interrupt priority level (IPL). The machine check exception vector (bits 0 to 1) must specify 1 or the operation of the processor is UNDEFINED. The exception is taken on the interrupt stack, and IPL is raised to 1F (hex).

The processor pushes a machine check stack frame onto the interrupt stack, consisting of a count longword, an implementation-dependent number of error report longwords, a PC and a PSL. The count longword reports the number of bytes of error report pushed. For example, if 4 longwords of error report are pushed, the count longword will contain 16 (decimal).

Software can decide, on the basis of the information presented, whether to abort the current process if the machine check came from the process. The machine check includes any uncorrected bus and memory errors and any other processor-detected errors. Some processor errors cannot ensure the state of the machine at all. For such errors, the state is preserved as well as possible, given the circumstances.



## A

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### Abort

- kernel stack not valid, E-9

Absolute expression, 3-8

Absolute mode, 5-12

- assembling relative mode as, 6-22

Absolute queue, 9-82

- manipulating, 9-85

ACBB (Add Compare and Branch Byte) instruction, 9-44

ACBD (Add Compare and Branch D\_floating) instruction, 9-44

ACBF (Add Compare and Branch F\_floating) instruction, 9-44

ACBG (Add Compare and Branch G\_floating) instruction, 9-44

ACBH (Add Compare and Branch H\_floating) instruction, 9-44

ACBL (Add Compare and Branch Long) instruction, 9-44

ACBW (Add Compare and Branch Word) instruction, 9-44

### Access mode

- vector, 10-16, 10-37, 10-44

ADAWI (Add Aligned Word Interlocked) instruction, 9-7

ADDB2 (Add Byte 2 Operand) instruction, 9-8

ADDB3 (Add Byte 3 Operand) instruction, 9-8

ADDD2 (Add D\_floating 2 Operand) instruction, 9-106

ADDD3 (Add D\_floating 3 Operand) instruction, 9-106

ADDF2 (Add F\_floating 2 Operand) instruction, 9-106

ADDF3 (Add F\_floating 3 Operand) instruction, 9-106

ADDG2 (ADD G\_floating 2 Operand) instruction, 9-106

ADDG3 (ADD G\_floating 3 Operand) instruction, 9-106

ADDH2 (ADD H\_floating 2 Operand) instruction, 9-106

ADDH3 (ADD H\_floating 3 Operand) instruction, 9-106

ADDL2 (Add Long 2 Operand) instruction, 9-8

ADDL3 (Add Long 3 Operand) instruction, 9-8

ADDP4 (Add Packed 4 Operand) instruction, 9-146

ADDP6 (Add Packed 6 Operand) instruction, 9-146

### Address

- access type, 8-16

- instructions, 9-33

- storage directive (.ADDRESS), 6-4

- translation vector, 10-41

- virtual, 8-2

.ADDRESS directive, 6-4

Addressing mode, 5-1

- absolute, 5-12, 6-22

- autodecrement, 5-6

- autoincrement, 5-4

- autoincrement deferred, 5-5

- branch, 5-16

- determining, 6-68

- displacement, 5-6

- displacement deferred, 5-8

- general, 5-14

- general register, 5-1

  - summary, 8-25

- immediate, 5-12

  - usage restricted in vector memory

    - instructions, 10-45, 10-47

- index, 5-14

- literal, 5-9, 5-13

- operand specifier formats, 8-16

- program counter, 5-10

  - summary, 8-26

- register, 5-3

- register deferred, 5-4

- relative, 5-10, 6-19, 6-22

- relative deferred, 5-11, 6-19

- summary, 5-1, C-9

Address storage directive (.ADDRESS), 6-4

ADDW2 (Add Word 2 Operand) instruction, 9-8

ADDW3 (Add Word 3 Operand) instruction, 9-8

ADWC (Add with Carry) instruction, 9-9

.ALIGN directive, 6-5

Alignment vector, 10-25, 10-43

AND operator, 3-15

AOBLEQ (Add One and Branch Less Than or Equal) instruction, 9-46

AOBLSS (Add One and Branch Less Than) instruction, 9-47

Architecture  
description of basic VAX, 8-1

Argument  
actual, 4-1  
in a macro, 4-1  
length, 6-64  
number of, 6-63

Arithmetic instruction  
decimal string, 9-142  
floating-point, 9-101  
integer, 9-5

Arithmetic shift operator, 3-14

.ASCIC directive, 6-8

.ASCID directive, 6-9

ASCII  
character set, A-1  
operator, 3-11

.ASCII directive, 6-10

ASCII string storage directive, 6-7  
counted (.ASCIC), 6-8  
string (.ASCII), 6-10  
string-descriptor (.ASCID), 6-9  
zero-terminated (.ASCIZ), 6-11

.ASCIZ directive, 6-11

ASHL (Arithmetic Shift Long) instruction, 9-10

ASHP (Arithmetic Shift and Round Packed) instruction, 9-148

ASHQ (Arithmetic Shift Quad) instruction, 9-10

Assembler directives,  
summary, C-1

Assembler notation, 10-14

Assembly termination, 6-25

Assembly termination directive (.END), 6-25

Assignment statement, 1-1, 3-15

Asynchronous memory management exception handling, 10-16, 10-26

Autodecrement mode, 5-6  
operand specifier format, 8-19

Autoincrement deferred mode, 5-5  
operand specifier format, 8-18

Autoincrement mode, 5-4  
operand specifier format, 8-18

## **B**

Base operand specifier, 8-23

BBC (Branch on Bit Clear) instruction, 9-50

BBC (Branch on Bit Clear and Clear) instruction, 9-51

BBCCI (Branch on Bit Clear and Clear Interlocked) instruction, 9-52

BBCS (Branch on Bit Clear and Set) instruction, 9-51

BBS (Branch on Bit Set) instruction, 9-50

BBSC (Branch on Bit Set and Clear) instruction, 9-51

BBS (Branch on Bit Set and Set) instruction, 9-51

BBSSI (Branch on Bit Set and Set Interlocked) instruction, 9-52

BCC (Branch on Carry Clear) instruction, 9-48

BCS (Branch on Carry Set) instruction, 9-48

BEQL (Branch on Equal) instruction, 9-48

BEQLU (Branch on Equal Unsigned) instruction, 9-48

BGEQ (Branch on Greater Than or Equal) instruction, 9-48

BGEQU (Branch on Greater Than or Equal Unsigned) instruction, 9-48

BGTR (Branch on Greater Than) instruction, 9-48

BGTRU (Branch on Greater Than Unsigned) instruction, 9-48

BICB2 (Bit Clear Byte 2 Operand) instruction, 9-11

BICB3 (Bit Clear Byte 3 Operand) instruction, 9-11

BICL2 (Bit Clear Long 2 Operand) instruction, 9-11

BICL3 (Bit Clear Long 3 Operand) instruction, 9-11

BICPSW (Bit Clear PSW) instruction, 9-71

BICW2 (Bit Clear Word 2 Operand) instruction, 9-11

BICW3 (Bit Clear Word 3 Operand) instruction, 9-11

Binary operator, 3-14  
summary, C-7

BISB2 (Bit Set Byte 2 Operand) instruction, 9-12

BISB3 (Bit Set Byte 3 Operand) instruction, 9-12

BISL2 (Bit Set Long 2 Operand) instruction, 9-12

BISL3 (Bit Set Long 3 Operand) instruction, 9-12

BISPSW (Bit Set PSW) instruction, 9-72

BISW2 (Bit Set Word 2 Operand) instruction, 9-12

BISW3 (Bit Set Word 3 Operand) instruction, 9-12

BITB (Bit Test Byte) instruction, 9-13

BITL (Bit Test Long) instruction, 9-13

BITW (Bit Test Word) instruction, 9-13

BLBC (Branch on Low Bit Clear) instruction, 9-53

BLBS (Branch on Low Bit Set) instruction, 9-53

BLEQ (Branch on Less Than or Equal) instruction, 9-48

BLEQU (Branch on Less Than or Equal Unsigned) instruction, 9-48

Block storage allocation directives (.BLKx), 6–12  
 BLSS (Branch on Less Than) instruction, 9–48  
 BLSSU (Branch on Less Than Unsigned) instruction, 9–48  
 BNEQ (Branch on Not Equal) instruction, 9–48  
 BNEQU (Branch on Not Equal Unsigned) instruction, 9–48  
 BPT (Breakpoint Fault) instruction, 9–73  
 Branch access type, 8–16  
 Branch mode, 5–16  
   operand specifier format, 8–26  
 BRB (Branch Byte Displacement) instruction, 9–54  
 BRW (Branch Word Displacement) instruction, 9–54  
 BSBB (Branch to Subroutine Byte Displacement) instruction, 9–55  
 BSBW (Branch to Subroutine Word Displacement) instruction, 9–55  
 BUGL (Bugcheck Longword Message Identifier) instruction, 9–196  
 BUGW (Bugcheck Word Message Identifier) instruction, 9–196  
 BVC (Branch on Overflow Clear) instruction, 9–48  
 BVS (Branch on Overflow Set) instruction, 9–48  
 Byte data type, 8–2  
 .BYTE directive, 6–14  
 Byte storage directive (.BYTE), 6–14

## C

Call frame, 9–63  
 CALLG (Call Procedure With General Argument List) instruction, 9–65  
 CALLS (Call Procedure with Stack Argument List) instruction, 9–67  
 Carry condition code (C), 8–14  
 CASEB (Case Byte) instruction, 9–56  
 CASEL (Case Long) instruction, 9–56  
 CASEW (Case Word) instruction, 9–56  
 Chaining of vector instructions, 10–18  
 Character set  
   in source statement, 3–1  
   special characters, C–5  
   table, A–1  
 Character string  
   data type, 8–7  
   instructions, 9–124  
   length, 6–64  
 CHME (Change Mode to Executive) instruction, 9–187  
 CHMK (Change Mode to Kernel) instruction, 9–187  
 CHMS (Change Mode to Supervisor) instruction, 9–187  
 CHMU (Change Mode to User) instruction, 9–187  
 CLRB (Clear Byte) instruction, 9–14  
 CLRD (Clear D\_floating) instruction, 9–107  
 CLRF (Clear F\_floating) instruction, 9–107  
 CLRG (Clear G\_floating) instruction, 9–107  
 CLRH (Clear H\_floating) instruction, 9–107  
 CLRL (Clear Long) instruction, 9–14  
 CLRO (Clear Octa) instruction, 9–14  
 CLRQ (Clear Quad) instruction, 9–14  
 CLRW (Clear Word) instruction, 9–14  
 CMPB (Compare Byte) instruction, 9–15  
 CMPC3 (Compare Characters 3 Operand) instruction, 9–126  
 CMPC5 (Compare Characters 5 Operand) instruction, 9–126  
 CMPD (Compare D\_floating) instruction, 9–108  
 CMPF (Compare F\_floating) instruction, 9–108  
 CMPI (Compare I\_floating) instruction, 9–108  
 CMPL (Compare Long) instruction, 9–15  
 CMPP3 (Compare Packed 3 Operand) instruction, 9–150  
 CMPP4 (Compare Packed 4 Operand) instruction, 9–150  
 CMPV (Compare Field) instruction, 9–38  
 CMPW (Compare Word) instruction, 9–15  
 CMPZV (Compare Zero Extended Field) instruction, 9–38  
 Colon (:)  
   in label field, 2–2  
 Complement operator, 3–13  
 Conditional assembly block directive  
   .ENDC, 6–26  
   (IF), 6–40  
   listing unsatisfied code, 6–88  
 Condition code, 8–13, 9–4  
   carry (C), 8–14  
   negative (N), 8–14  
   overflow (V), 8–14  
   zero (Z), 8–14  
 Context switch  
   scalar, 10–16, 10–17, 10–37  
   vector, 10–28  
 Continuation character (-)  
   in listing file, 3–8  
   in source statement, 2–1  
 Control instructions, 9–42  
 CRC (Calculate Cyclic Redundancy Check) instruction, 9–140  
 Created local label, 4–6  
   range, 3–7  
 .CROSS directive, 6–16  
 Cross-reference directive  
   .CROSS, 6–16  
   .NOCROSS, 6–16  
   (.NOCROSS), 6–66  
 Current location counter, 3–16

CVTBD (Convert Byte to D\_floating) instruction, 9–109

CVTBF (Convert Byte to F\_floating) instruction, 9–109

CVTBG (Convert Byte to G\_floating) instruction, 9–109

CVTBH (Convert Byte to H\_floating) instruction, 9–109

CVTBL (Convert Byte to Long) instruction, 9–16

CVTBW (Convert Byte to Word) instruction, 9–16

CVTDB (Convert D\_floating to Byte) instruction, 9–109

CVTDF (Convert D\_floating to F\_floating) instruction, 9–109

CVTDH (Convert D\_floating to H\_floating) instruction, 9–109

CVTDL (Convert D\_floating to Long) instruction, 9–109

CVTDW (Convert D\_floating to Word) instruction, 9–109

CVTFB (Convert F\_floating to Byte) instruction, 9–109

CVTFD (Convert F\_floating to D\_floating) instruction, 9–109

CVTFG (Convert F\_floating to G\_floating) instruction, 9–109

CVTFH (Convert F\_floating to H\_floating) instruction, 9–109

CVTFL (Convert F\_floating to Long) instruction, 9–109

CVTFW (Convert F\_floating to Word) instruction, 9–109

CVTGB (Convert G\_floating to Byte) instruction, 9–109

CVTGF (Convert G\_floating to F\_floating) instruction, 9–109

CVTGH (Convert G\_floating to H\_floating) instruction, 9–109

CVTGL (Convert G\_floating to Long) instruction, 9–109

CVTGW (Convert G\_floating to Word) instruction, 9–109

CVTHB (Convert H\_floating to Byte) instruction, 9–109

CVTHD (Convert H\_floating to D\_floating) instruction, 9–109

CVTHF (Convert H\_floating to F\_floating) instruction, 9–109

CVTHG (Convert H\_floating to G\_floating) instruction, 9–109

CVTHL (Convert H\_floating to Long) instruction, 9–109

CVTHW (Convert H\_floating to Word) instruction, 9–109

CVTLB (Convert Long to Byte) instruction, 9–16

CVTLD (Convert Long to D\_floating) instruction, 9–109

CVTLF (Convert Long to F\_floating) instruction, 9–109

CVTLG (Convert Long to G\_floating) instruction, 9–109

CVTLH (Convert Long to H\_floating) instruction, 9–109

CVTLP (Convert Long to Packed) instruction, 9–151

CVTLW (Convert Long to Word) instruction, 9–16

CVTPL (Convert Packed to Long) instruction, 9–152

CVTPS (Convert Packed to Leading Separate Numeric) instruction, 9–153

CVTPT (Convert Packed to Trailing Numeric) instruction, 9–155

CVTRDL (Convert Rounded D\_floating to Long) instruction, 9–109

CVTRFL (Convert Rounded F\_floating to Long) instruction, 9–109

CVTRGL (Convert Rounded G\_floating to Long) instruction, 9–109

CVTRHL (Convert Rounded H\_floating to Long) instruction, 9–109

CVTSP (Convert Leading Separate Numeric to Packed) instruction, 9–157

CVTTP (Convert Trailing Numeric to Packed) instruction, 9–159

CVTWB (Convert Word to Byte) instruction, 9–16

CVTWD (Convert Word to D\_floating) instruction, 9–109

CVTWF (Convert Word to F\_floating) instruction, 9–109

CVTWG (Convert Word to G\_floating) instruction, 9–109

CVTWH (Convert Word to H\_floating) instruction, 9–109

CVTWL (Convert Word to Long) instruction, 9–16

Cyclic redundancy check instruction, 9–139

## D

### Data storage directive

.ADDRESS, 6–4

.ASCIC, 6–8

.ASCID, 6–9

.ASCII, 6–10

.ASCIZ, 6–11

.BYTE, 6–14

.D\_FLOATING, 6–20

.F\_FLOATING, 6–35

.G\_FLOATING, 6–36

.H\_FLOATING, 6–38

.LONG, 6–56

.OCTA, 6–70

.PACKED, 6–74

.QUAD, 6–81

Data storage directive (cont'd)

- .SIGNED\_BYTE, 6-90
- .SIGNED\_WORD, 6-91
- .WORD, 6-101

Data type, 8-2

- byte, 8-2
- character string, 8-7
- floating-point, 8-4, 8-5, 8-6, 9-101
- integer, 8-2
- leading separate numeric string, 8-11
- longword, 8-3
- octaword, 8-3
- packed decimal string, 8-12
- quadword, 8-3
- string, 8-7
- trailing numeric string, 8-8
- variable-length bit field, 8-6
- word, 8-2

.DEBUG directive, 6-18

Debug directive (.DEBUG), 6-18

Debugger

- module name, 6-23
- routine name, 6-23

DECB (Decrement Byte) instruction, 9-17

Decimal/hexadecimal conversion, B-2

- table, B-1

Decimal overflow enable (DV), 8-15

Decimal string instructions, 9-142

DECL (Decrement Long) instruction, 9-17

DECW (Decrement Word) instruction, 9-17

.DEFAULT directive, 6-19

Default displacement length directive (.DEFAULT), 6-19

Default result

- vector arithmetic exceptions, 10-5, 10-26, 10-63

Delimiter

- string argument, 4-3

Dependencies

- vector results, 10-20

Direct assignment statement, 1-1, 3-15

Directive, 1-1, 6-1

- as operator, 2-3
- general assembler, 1-1, 6-1
- macro, 1-1, 6-1, 6-2
- summary, C-1

Disable assembler functions directive (.DISABLE), 6-21

Disabled fault

- vector processor, 10-27, 10-28

.DISABLE directive, 6-21

Displacement deferred mode, 5-8

- operand specifier formats, 8-20

Displacement mode, 5-6

- operand specifier formats, 8-19

DIVB2 (Divide Byte 2 Operand) instruction, 9-18

DIVB3 (Divide Byte 3 Operand) instruction, 9-18

DIVD2 (Divide D\_floating 2 Operand) instruction, 9-111

DIVD3 (Divide D\_floating 3 Operand) instruction, 9-111

DIVF2 (Divide F\_floating 2 Operand) instruction, 9-111

DIVF3 (Divide F\_floating 3 Operand) instruction, 9-111

DIVG2 (Divide G\_floating 2 Operand) instruction, 9-111

DIVG3 (Divide G\_floating 3 Operand) instruction, 9-111

DIVH2 (Divide H\_floating 2 Operand) instruction, 9-111

DIVH3 (Divide H\_floating 3 Operand) instruction, 9-111

Divide-by-zero trap, 8-15

DIVL2 (Divide Long 2 Operand) instruction, 9-18

DIVL3 (Divide Long 3 Operand) instruction, 9-18

DIVP (Divide Packed) instruction, 9-161

DIVW2 (Divide Word 2 Operand) instruction, 9-18

DIVW3 (Divide Word 3 Operand) instruction, 9-18

.DOUBLE directive, 6-20

D\_floating data type, 8-4, 9-102

.D\_FLOATING directive, 6-20

## E

Edit

- instruction, 9-167
- vector, 10-77
- pattern operator, 9-168, 9-170

EDITPC (Edit Packed to Character String) instruction, 9-168

EDIV (Extended Divide) instruction, 9-19

EMODD (Extended Multiply and Integerize D\_floating) instruction, 9-113

EMODF (Extended Multiply and Integerize F\_floating) instruction, 9-113

EMODG (Extended Multiply and Integerize G\_floating) instruction, 9-113

EMODH (Extended Multiply and Integerize H\_floating) instruction, 9-113

EMUL (Extended Multiply) instruction, 9-20

Enable assembler functions, 6-22

.ENABLE directive, 6-22, 6-34

.ENDC directive, 6-26

End conditional assembly directive (.END), 6-26

.END directive, 6-25

End macro definition directive (.ENDM), 6-27

.ENDM directive, 6-27

.ENDR directive, 6-28

.ENTRY directive, 6-29

- Entry mask, 9-63
- Entry point
  - defining, 6-29
- Entry point directive (.ENTRY), 6-29
- EO\$ADJUST\_INPUT (Adjust Input Length)
  - pattern operator, 9-172
- EO\$BLANK\_ZERO (Blank Backwards when Zero)
  - pattern operator, 9-173
- EO\$CLEAR\_SIGNIF (Clear Significance) pattern operator, 9-182
- EO\$END (End Edit) pattern operator, 9-174
- EO\$END\_FLOAT (End Floating Sign) pattern operator, 9-175
- EO\$FILL (Store Fill) pattern operator, 9-176
- EO\$FLOAT (Float Sign) pattern operator, 9-177
- EO\$INSERT (Insert Character) pattern operator, 9-178
- EO\$LOAD\_FILL (Load Fill Register) pattern operator, 9-179
- EO\$LOAD\_MINUS (Load Sign Register If Minus)
  - pattern operator, 9-179
- EO\$LOAD\_PLUS (Load Sign Register If Plus)
  - pattern operator, 9-179
- EO\$LOAD\_SIGN (Load Sign Register) pattern operator, 9-179
- EO\$MOVE (Move Digits) pattern operator, 9-180
- EO\$REPLACE\_SIGN (Replace Sign when Zero)
  - pattern operator, 9-181
- EO\$SET\_SIGNIF (Set Significance) pattern operator, 9-182
- EO\$STORE\_SIGN (Store Sign) pattern operator, 9-183
- .ERROR directive, 6-31
- ETYPE, 10-6, 10-64
- .EVEN directive, 6-33
- Exception, E-1
  - access control violation, E-3
  - arithmetic, E-1
  - arithmetic type code, E-1
  - breakpoint, E-7
  - change mode, E-7
  - compatibility mode, E-6
    - type code, E-6
  - control, 8-13
  - customer reserved opcode, E-5
  - decimal
    - string overflow, E-3
  - floating
    - divide-by-zero, E-2, E-3
    - overflow, E-2, E-3
    - underflow, E-2, E-3
  - instruction
    - emulation, E-6
    - execution, E-5
  - integer
    - divide-by-zero, E-2
    - overflow, E-2
  - kernel stack not valid, E-9

- Exception (cont'd)
  - machine check, E-9
  - memory management, E-3
  - operand reference, E-4
  - reserved
    - addressing mode, E-4
    - operand, E-4
  - subscript-range, E-3
  - trace, E-7
  - trace operation, E-7
  - translation not valid, E-4
  - vector processor, 10-10, 10-24, 10-30
    - arithmetic, 10-5, 10-19, 10-24, 10-26, 10-63
    - floating-point, 10-63
    - memory management, 10-25
    - Processor Status Longword, 8-14

#### Exception Condition Type

- See ETYPE

- Exclusive OR operator, 3-15

#### Execution model

- vector processor, 10-15

#### Expression, 3-8

- absolute, 3-8
- evaluation of, 3-8
- example of, 3-9
- external, 3-9
- global, 3-8
- relocatable, 3-8, 3-16

#### Extent

- syntax, 7-1

- .EXTERNAL directive, 6-34

- External expression, 3-9

- External symbol, 6-100

- attribute directive (.EXTERNAL), 6-34
- defining, 6-22, 6-34

- %EXTRACT operator, 4-10

- EXTV (Extract Field) instruction, 9-39

- EXTZV (Extract Zero Extended Field) instruction, 9-39

## F

---

#### Fault

- access control violation, E-3, E-4
- arithmetic, E-1
- arithmetic type code, E-1
- breakpoint, E-7
- customer reserved opcode, E-5
- floating
  - divide-by-zero, E-3
  - overflow, E-2, E-3
  - underflow, E-3
- instruction execution, E-5
- memory management, E-3
- privileged instruction, E-5
- reserved
  - addressing mode, E-4

Fault

- reserved (cont'd)
  - opcode, E-5
  - trace, E-7
  - translation not valid, E-4
- FFC (Find First Clear) instruction, 9-40
- FFS (Find First Set) instruction, 9-40
- Field, 2-1
  - comment, 2-1, 2-3
  - label, 2-1, 2-2
  - must be zero (MBZ), 7-1
  - operand, 2-3
  - operator, 2-3
  - read as zero (RAZ), 7-2
  - should be zero (SBZ), 7-2
  - variable-length bit, 8-6
- .FLOAT directive, 6-35
- Floating overflow fault, 8-15
- Floating-point
  - accuracy, 9-103
  - rounding, 9-103
  - zero, 9-102
- Floating-point constants (.D\_FLOATING), 6-20
- Floating-point data type, 8-4, 9-101
  - D\_floating, 8-4
  - G\_floating, 8-5
  - H\_floating, 8-6
- Floating-point instructions, 9-101
  - vector, 10-63
- Floating-point number, 9-101
  - format, 3-3
  - .F\_FLOATING, 6-35
  - .G\_FLOATING, 6-36
  - .H\_FLOATING, 6-38
  - in source statement, 3-3
  - rounding, 6-23
  - storage, 6-20
  - storing, 6-35, 6-36, 6-38
  - truncating, 6-23
- Floating-point operator, 3-13
- Floating-point storage directive
  - .D\_FLOATING, 6-20
  - (.F\_FLOATING), 6-35
  - (.G\_FLOATING), 6-36
- Floating underflow enable (FU), 8-14
- Formal argument, 4-1
- Frame
  - call, 9-63
  - stack, 9-63
- F\_floating data type, 8-4, 9-102
- .F\_FLOATING directive, 6-35

**G**

---

General mode, 5-14

General register mode, 5-1
 

- summary, 8-25

.GLOBAL directive, 6-37

Global expression, 3-8

Global label, 2-2

Global symbol, 3-6, 6-100
 

- attribute directive (.GLOBAL), 6-37
- defining, 6-22, 6-34, 6-37
- defining for shareable image, 6-95

G\_floating data type, 8-5, 9-102

.G\_FLOATING directive, 6-36

**H**

---

HALT (Halt) instruction, 9-74, 10-37
 

- interrupt stack not valid, E-9
- synchronizing vector memory before, 10-37

Hardware errors
 

- vector, 10-27, 10-42

Hexadecimal/decimal conversion, B-1
 

- table, B-1

H\_floating data type, 8-6

.H\_FLOATING directive, 6-38

H\_floating-point storage directive (.H\_FLOATING), 6-38

**I**

---

I/O space references
 

- vector, 10-25, 10-37, 10-42

.IDENT directive, 6-39

Identification directive (.IDENT), 6-39

.IF directive, 6-40

.IF\_FALSE directive, 6-43

.IF\_TRUE directive, 6-43

.IF\_TRUE\_FALSE directive, 6-43

.IIF directive, 6-46

Immediate conditional assembly block directive (.IIF), 6-46

Immediate mode, 5-12
 

- contrasted with literal mode, 5-13

Immediate mode addressing
 

- usage restricted in vector memory instructions, 10-45, 10-47

INCB (Increment Byte) instruction, 9-21

INCL (Increment Long) instruction, 9-21

Inclusive OR operator, 3-15

INCW (Increment Word) instruction, 9-21

Indefinite repeat argument directive (.IRP), 6-47

Indefinite repeat character directive (.IRPC), 6-49

INDEX (Compute Index) instruction, 9-75

Index mode, 5-14
 

- operand specifier format, 8-23

INSQHI (Insert Entry into Queue at Head, Interlocked) instruction, 9-89

INSQTI (Insert Entry into Queue at Tail, Interlocked) instruction, 9-91

INSQUE (Insert Entry in Queue) instruction, 9-93

Instruction, 1-1, 9-1

address, 9-33

arithmetic, 9-5, 9-101, 9-142

as operator, 2-3

character string, 9-124

control, 9-42

decimal string, 9-142

floating-point, 9-101

format, 8-15

integer, 9-5

logical, 9-5

packed decimal, 9-142

procedure call, 9-63

queue, 9-82

set, 9-1

string, 9-124, 9-142

variable-length bit field, 9-36

vector, 10-8, 10-15, 10-18

Instruction notation

operand specifier, 9-2

operation description, 9-3

INSV (Insert Field) instruction, 9-41

Integer

data type, 8-2

in source statement, 3-3

unsigned, 8-2, 8-3

Integer instructions, 9-5

vector, 10-52

Integer overflow enable (IV), 8-14

Interlocked instructions, 10-37

Internal processor register

See IPR

Interrupts, 10-37

IOTA (Generate Compressed Iota Vector)

instruction, 10-79

IPR (internal processor register)

vector, 10-3, 10-8

.IRPC directive, 6-49

.IRP directive, 6-47

---

## J

JMP (Jump) instruction, 9-58

JSB (Jump to Subroutine) instruction, 9-59

---

## K

Keyword argument, 4-2

---

## L

Label

created local, 4-6

global, 2-2

user-defined local, 3-6, 4-6

LDPCTX (Load Process Context) instruction, 9-191, 10-41

Leading separate numeric string

data type, 8-11

%LENGTH operator, 4-7

.LIBRARY directive, 6-51

.LINK directive, 6-52

/INCLUDE qualifier, 6-52

/LIBRARY qualifier, 6-52

/SELECTIVE\_SEARCH qualifier, 6-52

/SHAREABLE qualifier, 6-53

.LIST directive, 6-55

See also .SHOW directive

Listing control directive

.IDENT, 6-39

.LIST, 6-55

.NLIST, 6-65

.NOSHOW, 6-67, 6-88

.PAGE, 6-75

.SHOW, 6-88

Listing level count, 6-89

Listing table of contents, 6-93

Literal mode, 5-9

contrasted with immediate mode, 5-13

operand specifier format, 8-21

Local label

saving, 6-86

user-defined, 3-6

Local label block

ending, 6-22

starting, 6-22

Local symbol, 3-6

%LOCATE operator, 4-8

Location control directive

.ALIGN, 6-5

.BLKx, 6-12

Location counter alignment directive

(.ODD), 6-71

Location counter control directive

(.EVEN), 6-33

LOCC (Locate Character) instruction, 9-128

Logical AND operator

See AND operator

Logical exclusive OR operator

See Exclusive OR operator

Logical functions, vector, 10-59

Logical inclusive OR operator

See Inclusive OR operator

Logical instruction, 9-5

.LONG directive, 6-56

Longword data type, 8-3

Longword storage directive (.LONG), 6-56

## M

- Machine checks, 10–37, 10–42
- Macro, 4–1
  - nested, 4–4
  - passing numeric value to, 4–6
  - with the same name as an opcode, 6–58
- Macro argument, 4–1
  - actual, 4–1
  - concatenated, 4–5
  - delimited, 4–3, 4–5
  - formal, 4–1
  - keyword, 4–2
  - positional, 4–2
  - string, 4–3
- Macro call, 4–1
  - as operator, 2–3
  - listing, 6–88
  - number of arguments, 6–63
- Macro call directive (.MCALL), 6–60
- Macro definition, 4–1
  - default value, 4–2
  - end, 6–27
  - labeling in, 4–6
  - listing, 6–88
- Macro definition directive (.MACRO), 6–57
- Macro deletion directive (.MDELETE), 6–61
- .MACRO directive, 6–57
- Macro exit directive (.MEXIT), 6–62
- Macro expansion
  - listing, 6–88
  - printing, 4–1
  - terminating, 6–62
- Macroinstruction
  - See Macro
- Macro library
  - adding a name to, 6–51
- Macro library directive (.LIBRARY), 6–51
- Macro link directive (.LINK), 6–52
- Macro name, 3–5
- Macro operator
  - %EXTRACT, 4–10
  - %LENGTH, 4–7
  - %LOCATE, 4–8
  - string, 4–7
- Macro string operator
  - summary, C–8
- Mask
  - entry, 9–63
  - register, 3–12
  - register save, 6–29, 6–59
- .MASK directive, 6–59
- Masked vector operations, 10–9
- MATCHC (Match Characters) instruction, 9–129
- MBZ field, 7–1
- .MCALL directive, 6–60
- MCOMB (Move Complemented Byte) instruction, 9–22
- MCOML (Move Complemented Long) instruction, 9–22
- MCOMW (Move Complemented Word) instruction, 9–22
- .MDELETE directive, 6–61
- Memory
  - See Vector memory
- Memory management
  - exception, E–3
  - fault, E–3
  - vector, 10–41
    - memory management disabled, 10–42
    - TB, 10–6, 10–7, 10–16, 10–28, 10–29, 10–36, 10–41
- Memory management exceptions
  - vector, 10–25
    - asynchronous MME handling, 10–26
    - fault parameter, 10–25
      - PTE bit, 10–25
      - VAL bit, 10–25
      - VAS bit, 10–25
      - VIO bit, 10–25
    - fault stack frame, 10–25
    - synchronous MME handling, 10–26
    - system control block (SCB), 10–25
- Memory synchronization
  - required use of, 10–37
- Message display directive
  - (.ERROR), 6–31
  - (.PRINT), 6–76
- Message warning display directive
  - (.WARN), 6–98
- .MEXIT directive, 6–62
- MFPR (Move from Processor Register) instruction, 9–195
  - vector IPRs, 10–3, 10–7, 10–28
  - VPSR, 10–5, 10–27, 10–36
- MFVP (Move from Vector Processor) instruction, 10–16, 10–30
- MNEGB (Move Negated Byte) instruction, 9–23
- MNEGD (Move Negated D\_floating) instruction, 9–115
- MNEGF (Move Negated F\_floating) instruction, 9–115
- MNEGG (Move Negated G\_floating) instruction, 9–115
- MNEGH (Move Negated H\_floating) instruction, 9–115
- MNEGL (Move Negated Long) instruction, 9–23
- MNEGW (Move Negated Word) instruction, 9–23
- Modify access type, 8–15

Modify-fault  
     vector, 10–42  
 Module name  
     made available to debugger, 6–23  
 MOVAB (Move Address Byte) instruction, 9–34  
 MOVAD (Move Address D\_floating) instruction,  
     9–34  
 MOVAF (Move Address F\_floating) instruction,  
     9–34  
 MOVAG (Move Address G\_floating) instruction,  
     9–34  
 MOVAH (Move Address H\_floating) instruction,  
     9–34  
 MOVAL (Move Address Long) instruction, 9–34  
 MOVAO (Move Address Octa) instruction, 9–34  
 MOVAQ (Move Address Quad) instruction, 9–34  
 MOVAW (Move Address Word) instruction, 9–34  
 MOVB (Move Byte) instruction, 9–24  
 MOV C3 (Move Character 3 Operand) instruction,  
     9–130  
 MOV C5 (Move Character 5 Operand) instruction,  
     9–130  
 MOVD (Move D\_floating) instruction, 9–116  
 MOVF (Move F\_floating) instruction, 9–116  
 MOVG (Move G\_floating) instruction, 9–116  
 MOVH (Move H\_floating) instruction, 9–116  
 MOVL (Move Long) instruction, 9–24  
 MOV O (Move Octa) instruction, 9–24  
 MOV P (Move Packed) instruction, 9–163  
 MOVPSL (Move PSL) instruction, 9–77  
 MOVQ (Move Quad) instruction, 9–24  
 MOVTC (Move Translated Characters) instruction,  
     9–132  
 MOV TUC (Move Translated Until Character)  
     instruction, 9–134  
 MOVW (Move Word) instruction, 9–24  
 MOVZBL (Move Zero-Extended Byte to Long)  
     instruction, 9–25  
 MOVZBW (Move Zero-Extended Byte to Word)  
     instruction, 9–25  
 MOVZWL (Move Zero-Extended Word to Long)  
     instruction, 9–25  
 MSYNC (Memory Instruction Synchronization)  
     instruction, 10–30, 10–34, 10–37, 10–39,  
     10–81  
 MTPR (Move to Processor Register) instruction,  
     9–194, 10–41  
     vector IPRs, 10–7, 10–41  
 MTVP (Move to Vector Processor) instruction,  
     10–83  
 MULB2 (Multiply Byte 2 Operand) instruction,  
     9–26  
 MULB3 (Multiply Byte 3 Operand) instruction,  
     9–26  
 MULD2 (Multiply D\_floating 2 Operand)  
     instruction, 9–117

MULD3 (Multiply D\_floating 3 Operand)  
     instruction, 9–117  
 MULF2 (Multiply F\_floating 2 Operand)  
     instruction, 9–117  
 MULF3 (Multiply F\_floating 3 Operand)  
     instruction, 9–117  
 MULG2 (Multiply G\_floating 2 Operand)  
     instruction, 9–117  
 MULG3 (Multiply G\_floating 3 Operand)  
     instruction, 9–117  
 MULH2 (Multiply H\_floating 2 Operand)  
     instruction, 9–117  
 MULH3 (Multiply H\_floating 3 Operand)  
     instruction, 9–117  
 MULL2 (Multiply Long 2 Operand) instruction,  
     9–26  
 MULL3 (Multiply Long 3 Operand) instruction,  
     9–26  
 MULP (Multiply Packed) instruction, 9–164  
 MULW2 (Multiply Word 2 Operand) instruction,  
     9–26  
 MULW3 (Multiply Word 3 Operand) instruction,  
     9–26  
 Must Be Zero  
     See also MBZ  
     See Field

## N

---

.NARG directive, 6–63  
 .NCHR directive, 6–64  
 Negative condition code (N), 8–14  
 .NLIST directive, 6–65  
     See also .NOSHOW directive  
 .NOCROSS directive, 6–16, 6–66  
 NOP (No Operation) instruction, 9–78  
 .NOSHOW directive, 6–67, 6–88  
 .NTYPE directive, 6–68  
 Number  
     See also Integer, Floating-point number, and  
     Packed decimal string  
     in source statement, 3–2  
 Number of arguments directive (.NARG), 6–63  
 Number of characters directive (.NCHR), 6–64  
 Numeric control operator, 3–13  
 Numeric string  
     leading separate, 8–11  
     trailing, 8–8

## O

---

Object module  
     identifying, 6–39  
     naming, 6–94  
     title, 6–94  
 .OCTA directive, 6–70

- Octaword data type, 8–3
- Octaword storage directive (.OCTA), 6–70
- .ODD directive, 6–71
- One's complement
  - of expression, 3–13
- Opcode
  - creating, 6–72
  - defining, 6–82
  - format, 8–15
  - illegal vector, 10–14
  - redefining, 6–58, 6–72
  - summary, D–1
    - alphabetic order, D–1
    - numeric order, D–11
  - with the same name as a macro, 6–58
- Opcode definition directive (.OPDEF), 6–72
- .OPDEF directive, 6–72
- Operand, 2–3
  - determining addressing mode of, 6–68
  - primary, 8–23
  - reserved, 9–102, 9–103, 9–143
- Operand generation directive
  - (.REF16), 6–82
  - (.REF2), 6–82
  - (.REF4), 6–82
  - (.REF8), 6–82
- Operand specifier, 8–15
  - access type notation, 9–2
  - access types, 8–15
  - base, 8–23
  - data type notation, 9–2
  - data types, 8–16
  - notation, 9–2
  - restrictions on usage for vector instructions, 10–13
- Operand specifier addressing mode formats, 8–16
  - autodecrement mode, 8–19
  - autoincrement deferred mode, 8–18
  - autoincrement mode, 8–18
  - branch mode, 8–26
  - displacement deferred mode, 8–20
  - displacement mode, 8–19
  - index mode, 8–23
  - literal mode, 8–21
  - register deferred mode, 8–17
  - register mode, 8–17
- Operand type directive (.NTYPE), 6–68
- Operator, 2–3
  - AND, 3–15
  - arithmetic shift, 3–14
  - ASCII, 3–11
  - binary, 3–14, C–7
  - complement, 3–13
  - exclusive OR, 3–15
  - floating-point, 3–13
  - inclusive OR, 3–15
  - macro, 4–7
  - macro string, C–8

- Operator (cont'd)
  - numeric control, 3–13
  - pattern, 9–170
  - radix control, 3–10
  - register, 3–12
  - summary, C–6
  - textual, 3–11
  - unary, 3–9, C–7
- Overflow condition code (V), 8–14
- Overlapped vector instruction execution, 10–18

## P

---

- Packed decimal instructions, 9–142
- Packed decimal string, 9–142
  - data type, 8–12
  - format, 3–4
  - in source statement, 3–4
  - storing, 6–74
- Packed decimal string directive (.PACKED), 6–74
- .PACKED directive, 6–74
- Page ejection directive (.PAGE), 6–75
- Pattern operator, 9–168, 9–170
- Period (.)
  - current location counter, 3–16
- Permanent symbol, 3–4, 3–5
- Permanent symbol table, D–1
- POLYD (Polynomial Evaluation D\_floating)
  - instruction, 9–118
- POLYF (Polynomial Evaluation F\_floating)
  - instruction, 9–118
- POLYG (Polynomial Evaluation G\_floating)
  - instruction, 9–118
- POLYH (Polynomial Evaluation H\_floating)
  - instruction, 9–118
- POPL instruction, 9–27
- POPR (Pop Registers) instruction, 9–79
- Positional argument, 4–2
- Power failure, 10–37
- Primary operand, 8–23
- .PRINT directive, 6–76
- PROBER (Probe Read) instruction, 9–185
- PROBEW (Probe Write) instruction, 9–185
- Procedure call instructions, 9–63
- Processor status longword (PSL), 8–13
- Processor status word (PSW), 8–13
  - condition codes, 8–13
  - decimal overflow enable (DV), 8–15
  - floating underflow enable (FU), 8–14
  - integer overflow enable (IV), 8–14
  - trace trap enable (T), 8–14
- Program counter mode, 5–10
  - summary, 8–26
- Program execution time
  - delaying, 9–78
- Program section
  - absolute, 6–79, 6–80
  - alignment, 6–80

## Program section (cont'd)

- attributes, 6-77, 6-80
- defining, 6-77
- directive
  - (.PSECT), 6-77
  - (.RESTORE\_PSECT), 6-85
  - (.SAVE\_PSECT), 6-86
- name, 6-77, 6-80
- restoring context of, 6-85
- saving context of, 6-86
- saving local label, 6-86
- unnamed, 6-79, 6-80

.PSECT directive, 6-77

## PSL

See Processor status longword

## PSW

See Processor status word

PUSHAB (Push Address Byte) instruction, 9-35

PUSHAD (Push Address D\_floating) instruction, 9-35

PUSHAF (Push Address F\_floating) instruction, 9-35

PUSHAG (Push Address G\_floating) instruction, 9-35

PUSHAH (Push Address H\_floating) instruction, 9-35

PUSHAL (Push Address Long) instruction, 9-35

PUSHAQ (Push Address Quad) instruction, 9-35

PUSHAW (Push Address Word) instruction, 9-35

PUSHL (Push Long) instruction, 9-27

PUSHR (Push Registers) instruction, 9-80

## Q

---

.QUAD directive, 6-81

Quadword, 8-3

Quadword storage directive (.QUAD), 6-81

Queue, 9-82

- absolute, 9-82
- header, 9-82, 9-85
- inserting entries, 9-82, 9-85
- removing entries, 9-84, 9-87
- self-relative, 9-85

Queue instructions, 9-82

## R

---

Radix control operator, 3-10

Range

- syntax, 7-1

RAZ field, 7-2

Read access type, 8-15

Read As Zero

- See RAZ field

.REFn directive, 6-82

## Register

- vector, 10-1
  - control registers, 10-2
  - internal processor registers, 10-3

Register conflict

- vector, 10-20

Register deferred mode, 5-4

- operand specifier format, 8-17

Register mask operator, 3-12, 6-29

Register mode, 5-3

- operand specifier format, 8-17

Register name, 3-4, 3-6

Register save mask, 6-29, 6-59

Register save mask directive (.MASK), 6-59

REI (Return from Exception or Interrupt) instruction, 9-189

Relative deferred mode, 5-11

- setting default displacement length, 6-19

Relative mode, 5-10

- assembled as absolute mode, 6-22
- setting default displacement length, 6-19

Relocatable expression, 3-8

REMQHI (Remove Entry from Queue at Head, Interlocked) instruction, 9-95

REMQTI (Remove Entry from Queue at Tail, Interlocked) instruction, 9-97

REMQUE (Remove Entry from Queue) instruction, 9-99

Repeat block

- argument substitution, 6-47
- character substitution, 6-49
- end, 6-28
- listing range definitions of, 6-88
- listing range expansions of, 6-88
- listing specifiers, 6-88
- terminating repetition, 6-62

Repeat block directive (.REPEAT), 6-83

.REPEAT directive, 6-83

Repeat range end directive (.ENDR), 6-28

Reserved operand, 9-102, 9-103, 9-143

.RESTORE\_PSECT directive, 6-85

RET (Return from Procedure) instruction, 9-69

ROTL (Rotate Long) instruction, 9-28

Routine name

- made available to debugger, 6-23

RSB (Return from Subroutine) instruction, 9-60

## S

---

.SAVE\_PSECT directive, 6-86

SBWC (Subtract with Carry) instruction, 9-29

SBZ field, 7-2

Scalar/vector memory synchronization, 10-34

SCANC (Scan Characters) instruction, 9-136

Section name

- made available to debugger, 6-23

- Self-relative queue, 9–85
- Shift instruction
  - vector, 10–62
- Shift operator, 3–14
- Short literal mode
  - usage restricted in vector floating-point instructions, 10–13
- Should Be Zero
  - See SBZ field
- .SHOW directive, 6–88
- Signed byte storage directive (.SIGNED BYTE), 6–90
- Signed word storage directive (.SIGNED\_WORD), 6–91
- .SIGNED\_BYTE directive, 6–90
- .SIGNED\_WORD directive, 6–91
- Significance indicator, 9–182
- SKPC (Skip Character) instruction, 9–137
- SOBGEQ (Subtract One and Branch Greater Than or Equal) instruction, 9–61
- SOBGTR (Subtract One and Branch Greater Than) instruction, 9–62
- Source statement
  - See Statement
- SPANC (Span Characters) instruction, 9–138
- Stack frame, 9–63
- Statement, 1–1
  - character set, 3–1
  - comment, 2–3
  - continuation of, 2–1
  - format, 2–1
  - label, 2–2
  - operand, 2–3
  - operator, 2–3, C–6
  - special characters, C–5
- Stride
  - vector, 10–43
- String argument, 4–3
- String data type
  - character, 8–7
  - leading separate numeric, 8–11
  - packed decimal, 8–12
  - trailing numeric, 8–8
- String instructions, 9–124, 9–142
- String operator
  - in macro, 4–7
- SUBB2 (Subtract Byte 2 Operand) instruction, 9–30
- SUBB3 (Subtract Byte 3 Operand) instruction, 9–30
- Subconditional assembly block directive, 6–43
  - .IF\_FALSE, 6–43
  - .IF\_TRUE, 6–43
  - .IF\_TRUE\_FALSE, 6–43
- Subconditional assembly block directive (.IF\_x), 6–43
- SUBD2 (Subtract D\_floating 2 Operand) instruction, 9–121
- SUBD3 (Subtract D\_floating 3 Operand) instruction, 9–121
- SUBF2 (Subtract F\_floating 2 Operand) instruction, 9–121
- SUBF3 (Subtract F\_floating 3 Operand) instruction, 9–121
- SUBG2 (Subtract G\_floating 2 Operand) instruction, 9–121
- SUBG3 (Subtract G\_floating 3 Operand) instruction, 9–121
- SUBH2 (Subtract H\_floating 2 Operand) instruction, 9–121
- SUBH3 (Subtract H\_floating 3 Operand) instruction, 9–121
- SUBL2 (Subtract Long 2 Operand) instruction, 9–30
- SUBL3 (Subtract Long 3 Operand) instruction, 9–30
- SUBP4 (Subtract Packed 4 Operand) instruction, 9–165
- SUBP6 (Subtract Packed 6 Operand) instruction, 9–165
- .SUBTITLE directive, 6–93
- Subtitle listing control directive (.SUBTITLE), 6–93
- SUBW2 (Subtract Word 2 Operand) instruction, 9–30
- SUBW3 (Subtract Word 3 Operand) instruction, 9–30
- Summary of OPCODES
  - alphabetic order, D–1
  - numeric order, D–11
- SVPCTX (Save Process Context) instruction, 9–193
- Symbol, 3–4
  - cross-referencing, 6–16, 6–66
  - determining value of, 3–5
  - external, 6–34, 6–100
  - global, 3–6, 6–34, 6–37, 6–95, 6–100
  - in operand field, 3–6
  - in operator field, 3–5
  - local, 3–6
  - macro name, 3–5
  - made available to debugger, 6–22
  - permanent, 3–4, 3–5
  - register name, 3–4, 3–6
  - suppressing, 6–23
  - transferral to VAX Symbolic Debugger, 6–18
  - undefined, 6–22
  - user-defined, 3–5, 3–6
- Symbol attribute directive (.WEAK), 6–100

Symbol definition for shareable image, 6–95  
Symbol for shareable image directive  
(.TRANSFER), 6–95  
SYNC (Scalar/Vector Instruction Synchronization)  
instruction, 10–16, 10–33, 10–81  
Synchronization, 10–33  
Synchronous memory management exception  
handling, 10–26  
System Control Block (SCB) vector, 10–25  
System failure, E–9

## T

---

Tab stops  
in source statement, 2–1  
TB (Translation buffer)  
vector, 10–6, 10–7, 10–16, 10–28, 10–29,  
10–36, 10–41  
TBIA (TB Invalidate All) instruction, 10–41  
TBIS (TB Invalidate Single) instruction, 10–41  
Term in MACRO statement, 3–8  
Textual operator, 3–11  
.TITLE directive, 6–94  
Title listing control directive  
(.TITLE), 6–94  
Traceback, 6–23  
Trace trap enable (T), 8–14  
Trailing numeric string  
data type, 8–8  
.TRANSFER directive, 6–95  
Translation buffer  
See TB  
Trap  
arithmetic, E–1  
arithmetic type code, E–1  
change mode, E–7  
decimal  
string overflow, E–3  
decimal overflow, 8–15  
divide by zero, 8–15  
floating  
divide-by-zero, E–2  
overflow, E–2  
underflow, E–2  
integer  
divide-by-zero, E–2  
overflow, E–2  
integer overflow, 8–14  
subscript-range, E–3  
trace, 8–14  
TSTB (Test Byte) instruction, 9–31  
TSTD (Test D\_floating) instruction, 9–123  
TSTF (Test F\_floating) instruction, 9–123  
TSTG (Test G\_floating) instruction, 9–123  
TSTH (Test H\_floating) instruction, 9–123

TSTL (Test Long) instruction, 9–31  
TSTW (Test Word) instruction, 9–31

## U

---

Unary operator, 3–9  
summary, C–7  
UNDEFINED results, 7–1  
UNPREDICTABLE results, 7–1  
User-defined local label, 3–6  
range, 3–7  
User-defined symbol, 3–5, 3–6

## V

---

VADD (Vector Floating Add) instruction, 10–65  
VADDL (Vector Integer Add) instruction, 10–52  
VAER (Vector Arithmetic Exception Register),  
10–5  
Variable bit base address access type, 8–16  
Variable-length bit field  
bytes referenced, 8–7  
data type, 8–6  
Variable-length bit field instructions, 9–36  
VAX architecture, 8–1  
scalar, 8–2  
vector, 8–2  
VAX condition codes, 10–14  
VBIC (Vector Bit Clear) instruction, 10–59  
VBIS (Vector Bit Set) instruction, 10–59  
VCMP (Vector Floating Compare) instruction,  
10–67  
VCMPPL (Vector Integer Compare) instruction,  
10–54  
VCR (Vector Count Register), 10–3, 10–81, 10–83  
VDIV (Vector Floating Divide) instruction, 10–72  
Vector address translation, 10–41  
Vector code  
assembling, 6–23  
Vector control word, 10–8, 10–10, 10–14  
EXC (Exception Enable) bit, 10–9, 10–10,  
10–11, 10–14, 10–25, 10–53, 10–56, 10–58,  
10–63, 10–66, 10–71, 10–73, 10–75, 10–77  
MI (Modify Intent) bit, 10–9, 10–10, 10–15,  
10–45, 10–47  
MOE (Masked Operations Enable) bit, 10–9,  
10–14  
MTF (Match True/False) bit, 10–9, 10–14  
register specifier fields, 10–10  
Vector Count Register  
See VCR  
Vector instruction  
decoding, 10–15  
execution, 10–18  
formats, 10–8

Vector Length Register  
     See VLR  
 Vector Logical Functions, 10–59  
 Vector Mask Register  
     See VMR  
 Vector memory  
     accessing page tables, 10–42  
     access mode, 10–16, 10–44  
     alignment, 10–43  
     HALT considerations, 10–37  
     indicating intent to modify, 10–10  
     instructions, 10–43  
     management  
         See Memory management  
     required use of synchronization instructions, 10–37  
     scalar/vector synchronization of, 10–34  
     stride, 10–43  
 Vector Memory Activity Check Register  
     See VMAC  
 Vector opcode  
     See Appendix D  
 Vector processor disabled, 10–27, 10–28  
 Vector Processor Status Register  
     See VPSR  
 Vector registers, 10–1  
 Vector State Address Register  
     See VSAR  
 VGATH (Gather Memory Data into Vector Register) instruction, 10–10, 10–13, 10–39  
 Virtual address, 8–2  
 Virtual-machine processor status longword (VMPSL), 9–189  
 VLD (Load Memory Data into Vector Register) instruction, 10–10, 10–13, 10–39, 10–45  
 VLR (Vector Length Register), 10–2, 10–81, 10–83  
 VMAC (Vector Memory Activity Check) Register, 10–6, 10–17, 10–35, 10–37, 10–39, 10–42  
 VMERGE (Vector Merge) instruction, 10–78  
 VMPSL  
     See Virtual-machine processor status longword  
 VMR (Vector Mask Register), 10–2, 10–20, 10–81, 10–83  
 VMUL (Vector Floating Multiply) instruction, 10–74  
 VMULL (Vector Integer Multiply) instruction, 10–56  
 VPSR (Vector Processor Status Register), 10–4, 10–5  
     AEX (Arithmetic Exception) bit, 10–4, 10–27, 10–28, 10–29, 10–30  
     BSY (Busy) bit, 10–4, 10–5, 10–7, 10–17, 10–29, 10–34, 10–42  
     IMP (Implementation-Specific Hardware Error) bit, 10–4, 10–27, 10–28, 10–29, 10–30, 10–42, 10–43

VPSR (Vector Processor Status Register) (cont'd)  
     IVO (Illegal Vector Opcode) bit, 10–4, 10–14, 10–27, 10–28, 10–29, 10–30  
     MF (Memory Fault) bit, 10–4, 10–16, 10–26, 10–30  
     PMF (Pending Memory Fault) bit, 10–4, 10–16, 10–26, 10–29, 10–30  
     RLD (State Reload) bit, 10–4, 10–5, 10–30  
     RST (State Reset) bit, 10–4, 10–5, 10–7, 10–29, 10–36  
     STS (State Store) bit, 10–4, 10–5, 10–29  
     VEN (Enable) bit, 10–4, 10–5, 10–15, 10–17, 10–27, 10–28, 10–29, 10–30, 10–42, 10–43  
 VSAR (Vector State Address Register), 10–7  
 VSCAT (Scatter Vector Register Data into Memory) instruction, 10–10, 10–13, 10–39, 10–51  
 VSL (Vector Shift Logical) instruction, 10–62  
 VST (Store Vector Register Data into Memory) instruction, 10–10, 10–13, 10–39, 10–49  
 VSUB (Vector Floating Subtract) instruction, 10–76  
 VSUBL (Vector Integer Subtract) instruction, 10–58  
 VSYNC (Synchronize Vector Memory Access) instruction, 10–36, 10–37, 10–39, 10–84  
 VTBIA (Vector TB Invalidate All) instruction, 10–6, 10–7, 10–28, 10–29, 10–36, 10–41  
 VVCVT (Vector Convert) instruction, 10–70  
 VXOR (Vector Exclusive Or) instruction, 10–59

## W

---

.WARN directive, 6–98  
 .WEAK directive, 6–100  
 Word data type, 8–2  
 .WORD directive, 6–101  
 Word storage directive (.WORD), 6–101  
 Write access type, 8–15

## X

---

XFC (Extended Function Call) instruction, 9–81  
 XORB2 (Exclusive OR Byte 2 Operand) instruction, 9–32  
 XORB3 (Exclusive OR Byte 3 Operand) instruction, 9–32  
 XORL2 (Exclusive OR Long 2 Operand) instruction, 9–32  
 XORL3 (Exclusive OR Long 3 Operand) instruction, 9–32  
 XORW2 (Exclusive OR Word 2 Operand) instruction, 9–32  
 XORW3 (Exclusive OR Word 3 Operand) instruction, 9–32

## **Z**

---

Zero condition code (Z), 8-14